FAME TIM 3/20/01
ADCS

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Topics

- Mission Requirement Changes
- SRR Trades & Issues/Concerns
- ADCS Baseline Evolution
- Requested TIM Topics
  - Primary Precession Control Method
  - Precession Control Backup Method
  - Nutation Damper Trades
  - ACS Propellant & Thruster Configuration
- Related Investigations Of Interest
  - Trim Areas & CP-To-CM Balancing
  - Spin Rate Control Methods
  - On-Orbit Spin Balance & CM Estimation
  - Optical Property Verification Testing Plan
- ADCS Action Item Summary

Mission Requirement Changes (1 Of 3)

- Attitude Knowledge For Instrument Attitude Acquisition
  - Relaxation Of Requirement
  - Lower Level Requirements Still Need To Be Derived
- Spin Period Change
  - Relaxation Of Requirement

Mission Requirement Changes (2 Of 3)

Attitude Knowledge For Instrument Attitude Acquis

- SRR requirement from S/C BUS TOP RQMTS section, page 6:

Acquisition Mode		
Location of Instrument Acquisition Window Based on Star Tracker Data	Star Tracker Accuracy Attitude Prediction Accuracy	Combine to 50 μrad
	CCD Location Accuracy	TBD
	Star Tracker to Instrument Boresight	TBD

- SRR requirement from S/C SSS - ADCS section, page ?
  - Attitude Knowledge: 50 μrad per axis
- Revised requirement is: Acquisition Window is +/- 300 μrad (3σ)

- Assumptions:
  - 1Hz attitude solution provided to the instrument by the S/C bus with this accuracy
  - Attitude Kalman filter using data from the ST and IMU

Acquisition Mode (+/- 300 μrad (3σ))		
Location of Instrument Acquisition Window Based on Star Tracker Data	Star Tracker Accuracy	+/- 265μrad (3σ)
	Attitude Prediction Accuracy	
	CCD Location Accuracy	+/- 100μrad (3σ)
	Star Tracker to Instrument Boresight	+/- 100μrad (3σ)

Proposed Breakdown
Is RSS OK?
Is Split OK?

Mission Requirement Changes (3 Of 3)

Instrument Spin Period Change

- **SRR requirement from S/C BUS TOP RQMTS section, page 3 & S/C BUS - ADCS section, page 2 :**
  - **Spacecraft Rotation Period: 40 +/- 2 Min**
- **Revised requirement is:**
  - **Spacecraft Rotation Period: 40 +/- 4 Min**
- **Assumptions:**
  - **Assume (3σ)**

Trade Studies From SRR

- Sensor (ST, IMU, SS) Selection
  - Performance Requirements, Vendors
  - Sensor Placement Vs Performance
- Passive vs. Active Nutation Damping
  - Active Nutation Damping Mechanism
    - Magnetic (Electromagnetic Torquers) vs. Solar (Trim Tabs)
  - Passive Nutation Damping Mechanism
    - Requirements, Build/Buy, Other Inherent Damping (Propellant Or Structure)
    - Deployable/Retractable Nutation Damping Mechanism
- Backup Science Acquisition Concept
  - Mass Expulsion (Thrusters) vs. Magnetics (Electromagnetic Torquers) in Comparison to Baseline Concept (Solar Precession)
- Trim Tab vs. Thermal Radiation Patch

Issues / Challenges From SRR

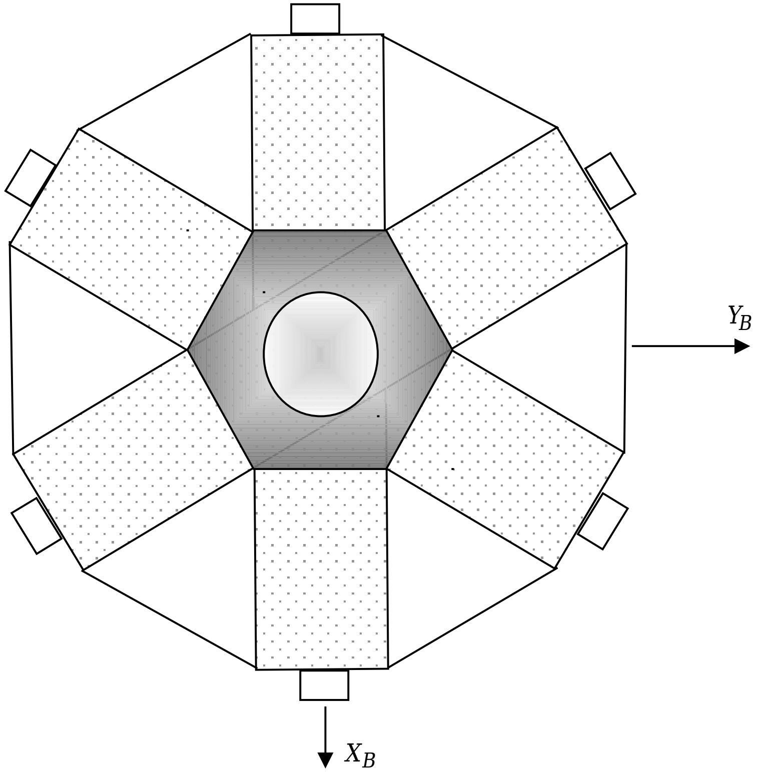
- Optical Properties Knowledge (BOL and EOL) and Balancing
- Mass Properties Control: CG Offset, Spin Axis Misalignment
- Thermal Radiation Disturbance Torque Knowledge and Control
- Trim Tab / Trim Mass Control Strategy
- Nutation Damping Mechanism Selection
- S/C Magnetic Dipole Measurement

ADCS Baseline Evolution

Technical Interchange Meeting
March 20-21, 2001
Naval Research Laboratory

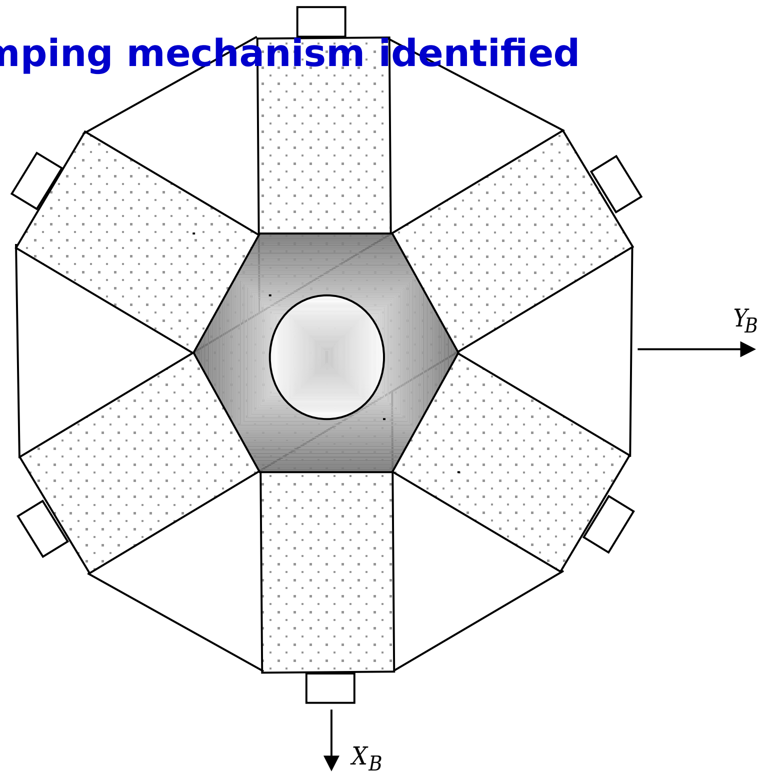
CSR Baseline

- Swept-back sun shield for coarse solar radiation torque adjustment prior to launch
- Six trim tabs for solar radiation torque adjustment through uniform deflection & individual CP variations between arrays through individual deflection
- Trim masses for CM control & principal axis misalignment
- Acquisition of instrument pointing mode with thrusters



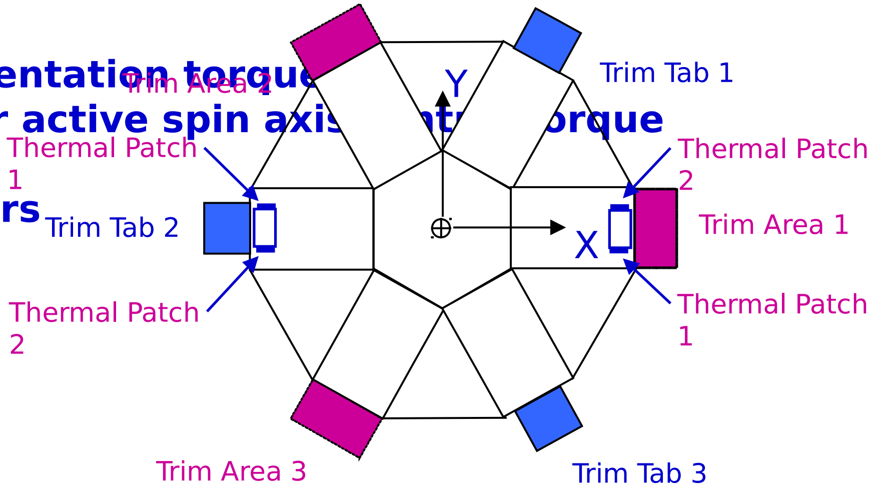
SRR Baseline

- Swept-back sun shield for coarse solar radiation torque adjustment prior to launch
- Six trim tabs for solar radiation torque adjustment through uniform deflection & individual CP variations between arrays through individual deflection
- Trim masses for CM control & principal axis misalignment
    - Added accelerometers for CM balancing
- Acquisition of instrument pointing mode with thrusters
- No fine spin rate control
- No active or passive damping mechanism identified



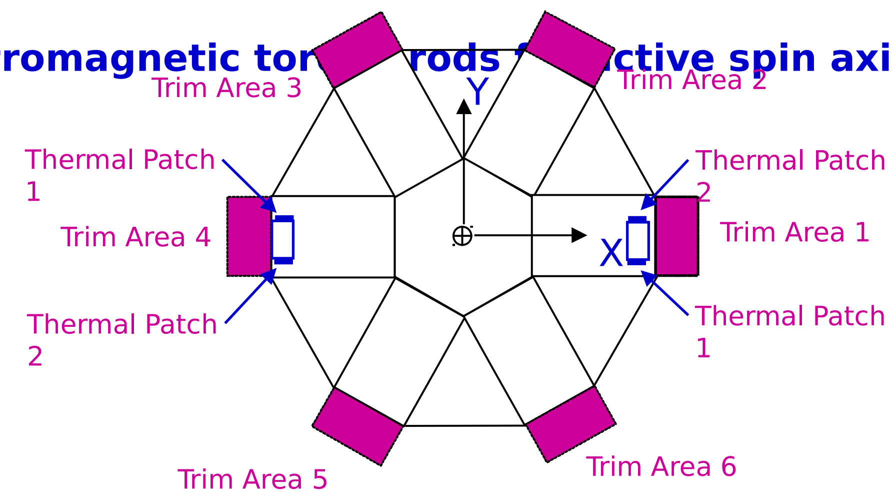
3/20-21/01 TIM Baseline (SRR -> PDR)

- Swept-back sun shield for coarse solar radiation torque adjustment prior to launch
- Three trim tabs for solar radiation torque bias adjustment through uniform deflection
- Three trim areas for individual CP variations between arrays through individual changes & for CP to CM balancing
  - Replaces use of trim tabs for individual CP adjustments
  - Better method of CP control
- Trim masses for principal axis misalignment only
  - Removed four balance masses used for CM balancing
  - Reduced balance mass dramatically
- Acquisition of instrument pointing mode with thrusters
- Two sets of thermal patches for fine spin axis bias torque balancing
  - New capability added
- Z-axis electromagnetic torque rod for active damping of nutation angle transients
  - New capability added
  - Also provides solar precession augmentation torque
- X- & Y-axis electromagnetic torque rods for active spin axis control torque
  - New capability added
  - Backup to thermal patches & thrusters



Potential Baseline (Pre-PDR)

- On-orbit capable swept-back sun shield for coarse/fine solar radiation bias torque adjustment
  - Adds six strut motors
  - Removes three trim tabs
  - Provides larger balancing range
- Six trim areas for individual CP variations between arrays through individual changes & for CP to CM balancing
  - Replaced removed trim tabs with three additional trim areas
  - Provides larger balancing range
- Trim masses for principal axis misalignment only
- Acquisition of instrument pointing mode with thrusters
- Two sets of thermal patches for fine spin axis bias & oscillating torque balancing
  - Improves spin rate stability
- Z-axis electromagnetic torque rod for active damping of nutation angle transients
- X- & Y-axis electromagnetic tor rods f ctive spin axis torque control



Instrument Operation Baseline ADCS Design (1 Of 2)

- **On-Orbit Operation**
  - **On-Orbit S/C Balancing Prior To Instrument Operation**
  - **Solar Pressure For Smooth Spin Axis Precession**
  - **Spin Rate Disturbance Torque Balancing**
  - **Balancing During Instrument Operation As Needed**
  - **Transient Event Disturbances Actively Damped When Required**
  - **Solar Precession Augmentation When Required**
  - **Spin Rate Change Augmentation When Required**
- **On-Orbit Balancing Actuators:**
  - **Two Balance Masses For Dynamic Balance**
  - **Three Trim Tabs For Solar Precession Bias Torque Balance**
  - **Three Trim Areas For CP/CM Balance**
  - **Two Sets Of Thermal Patches For Spin Axis Torque Balance**

Instrument Operation Baseline ADCS Design (2 Of 2)

- **On-Orbit Control Actuators:**
  - **Thrusters For Instrument Spin Rate & Sun Angle Acquisition**
  - **Three Electromagnetic Torquers**
    - **Transient Nutation Damping**
    - **Solar Precession Augmentation**
    - **Coarse Spin Rate Adjustment**
- **Ground Balancing Process:**
  - **Inertia Matrix Requirements Specified To Minimize Gravity Gradient Torque**
  - **Residual Magnetic Dipole Requirements Specified To Minimize Magnetic Torque**
  - **Structure & Mechanism Design To Maximize Symmetry**
  - **Sun Shield Material Selection**
    - **Uniformity Around Shield**
    - **Uniformity Of Degradation**
    - **Knowledge Of Optical Properties (Either Existing Or To Be Tested)**
  - **Static & Dynamic Balancing To Within Capability Of On-Orbit Balancing**

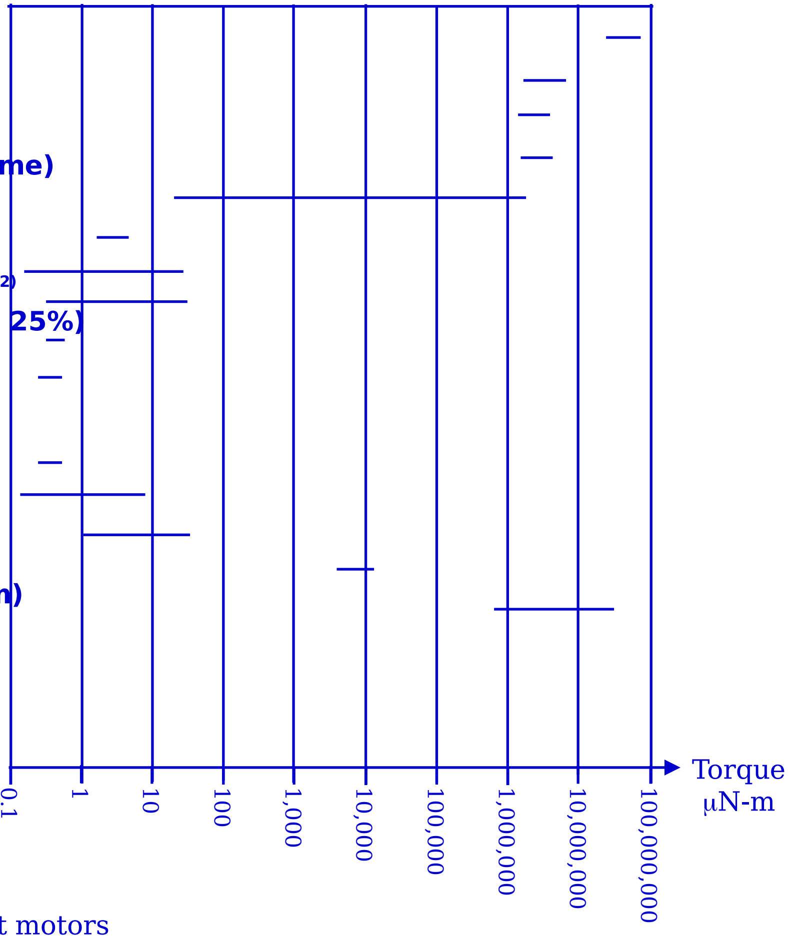
Mission Torque Summary

Control Requirements

- **ANC Torque Required (~ 30 - 80 N-m)**
- **Flt Vehicle Spin Up/Down (<10 Min Duration)**
- **DV Attitude Control**
- **Instrument Spin Rate Tolerance (50 & 20 msec on time)**
- **Instrument Spin Up (< 1 Day - 1 Sec Duration)**
- **Solar Precession Torque Required (5.8 μN-m)**
- **Solar Precession Sweep Angle Change (10 - 0 Deg)** (2)
- **Solar Precession Specular/Diffuse Ratio Change (+/- 25%)**
- **Disturbance Torque Maximum Allowable (1 μN-m)**
- **Cyclic Or Bias Spin Rate Control(0.35 μN-m)**

Possible Actuators (1)

- **Spin Thermal Patch Or Roll Trim Tabs (0.4 μN-m)**
- **Trim Tab Sweep Angle Change (0 - 40 Deg)**
- **Electromagnetic Torquer (10 - 200 Am^2)**
- **Reaction Wheel Minimum Torque Capability (7 mN-m)**
- **Thrusters (1 - 22 N w/1 m moment arm)**



(1) Not all actuators listed are available on FAME
(2) Could be converted to an actuator with addition of strut motors

Primary Precession Control Method

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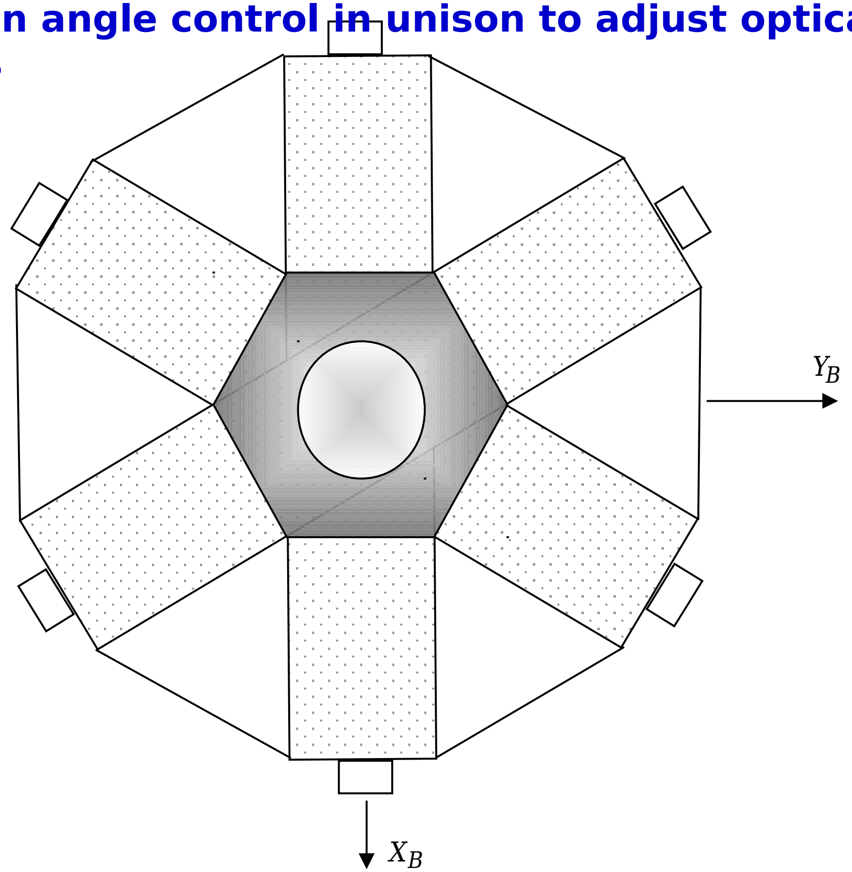
SRR Baseline Precession Rate Control

- **Swept-back sun shield for coarse solar radiation torque adjustment**
  - **9.5 degrees, without thermal radiation torque compensation**

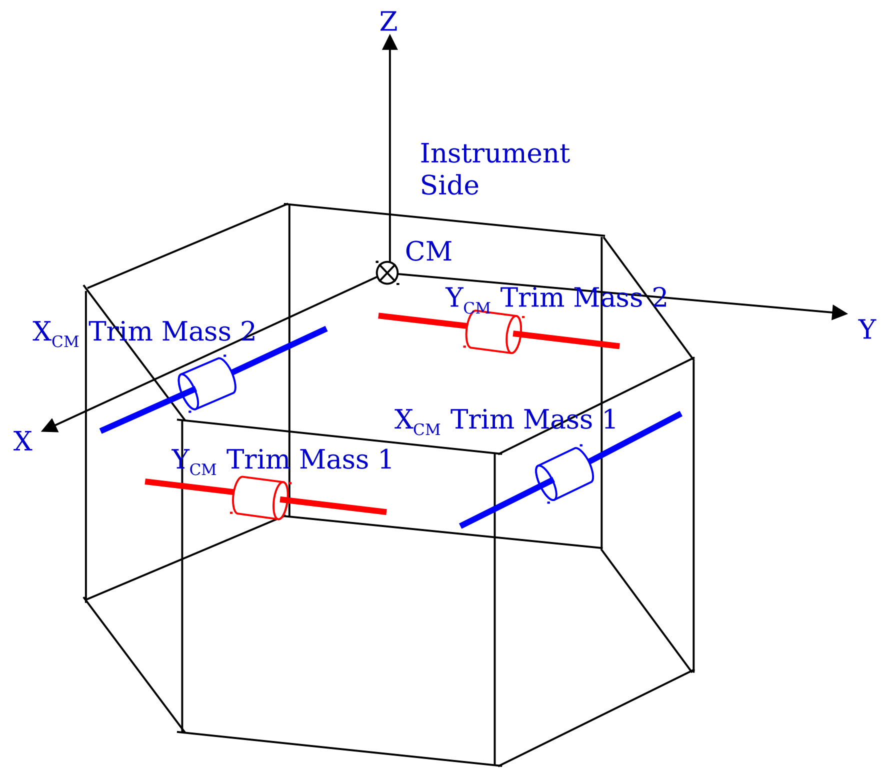
- **Six trim tabs (0.5 m by 0.5 m, each)**

- **Trim tab deflection angle control in unison to adjust optical property variations**



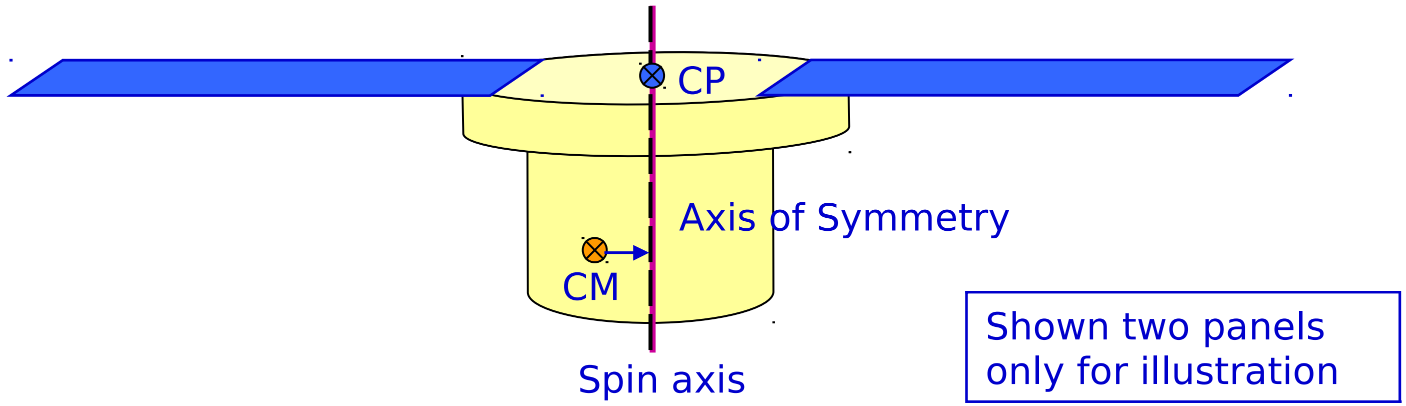
SRR Baseline CP-CM Offset Control

- **Trim mass system for radial CM control**
  - **- 10 mm radius CM offset control capability**
  - **- Weight penalty of the four trim mass system: 110 lb**

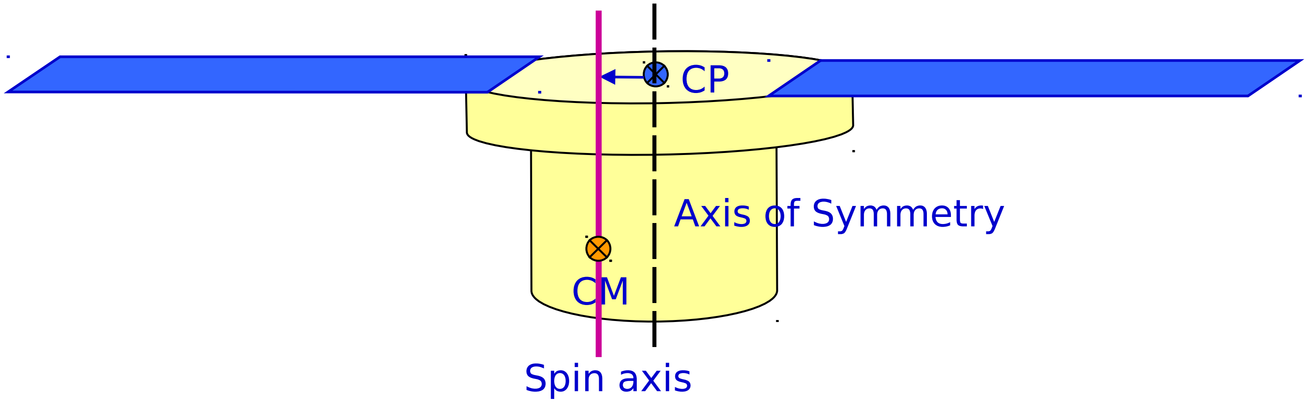


CP-CM Offset Control Concept

- **CM (center of mass) Control: move CM to align with CP**



- **CP (Center of Pressure) Control: move CP to align with CM**



CP-CM Offset Control Options

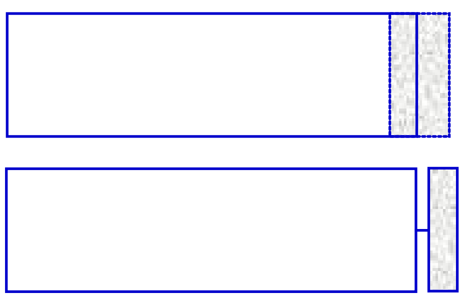
- Radial CP control Options
  - Trim tabs

- Pitch up and down
- Modulate the deflection at spin rate for sun shield CP control

- Optical property control patches

- Rotate the wheel
- Optical property control may require modul of the rotation angle at spin rate

- Area control tabs

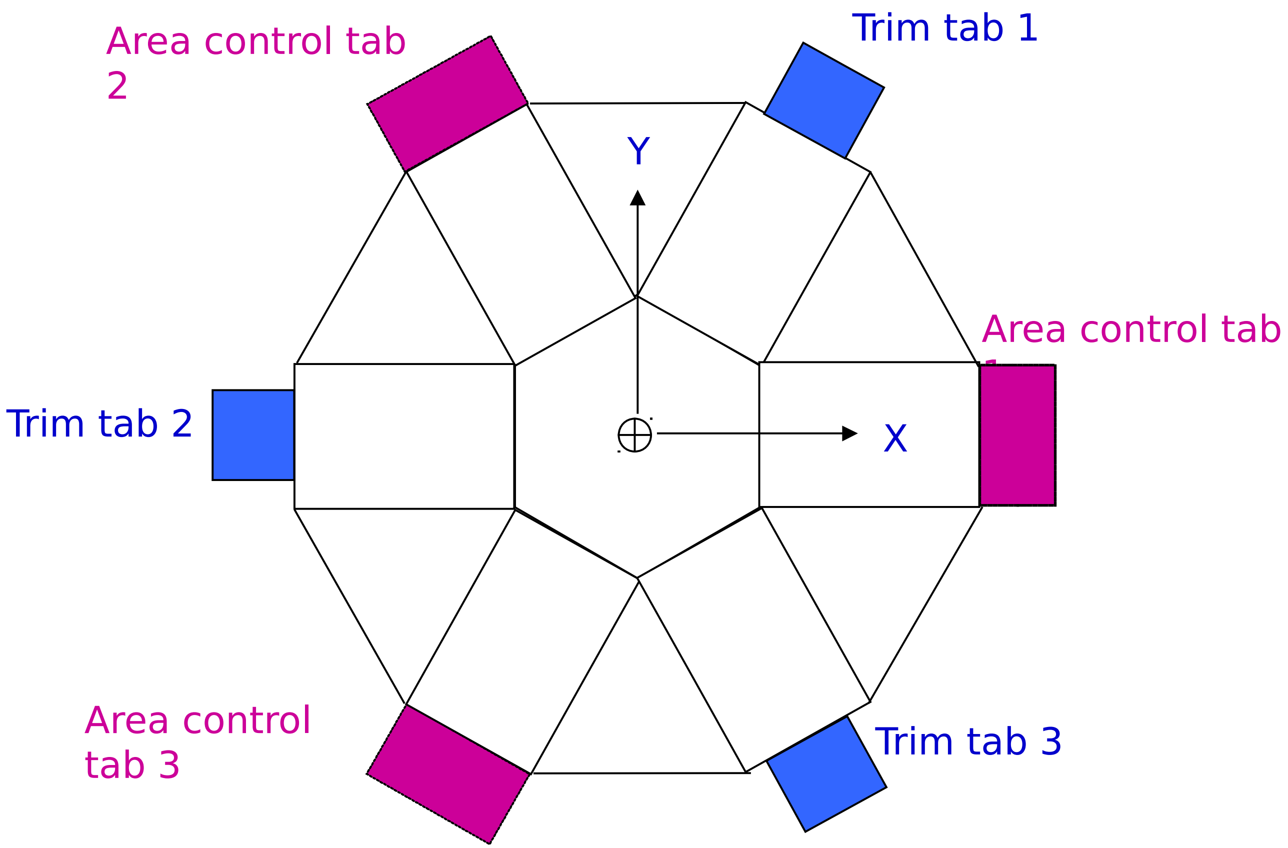


- Slide in and out for sun shield CP control
- No modulation ✓

- Replaces radial CM control trim mass assembly

Combined Precession Rate / CP-CM Offset Control: Combination of Trim and Area Control Tabs

- **Area control tabs for radial CP control**
- **Trim tabs for precession rate control**



Updated Mass Property Requirements (2/26/01)

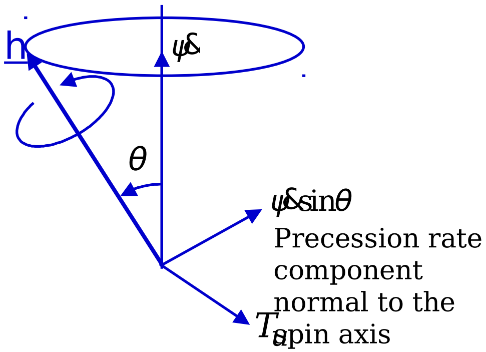
- **Prior to On-Orbit Trimming**

Items	SRR	Updated	Remarks
Izz (spin axis, kg-m^2)	400 +/- 10%	800 +/- 10%	Weight increase
Ixx	0.89 Izz ≤ Ixx ≤ 0.91 Izz	0.89 Izz ≤ Ixx ≤ 0.91 Izz	
Iyy	0.89 Izz ≤ Ixx ≤ 0.91 Izz	0.89 Izz ≤ Ixx ≤ 0.91 Izz	
|Ixx-Iyy|	≤ 0.01 Izz	≤ 0.02 Izz (TBR)	
|Ixy|	≤ 0.01 Izz	≤ 0.025 Izz (TBR)	
|Ixz|	≤ 0.0012 Izz	≤ 5.7e-4 Izz (TBR)	0.5 deg spin axis misalignment
|Iyz|	≤ 0.0012 Izz	≤ 5.7e-4 Izz (TBR)	9.5e-6 Izz (TBR) for 30 as misalignment
|XCM|	≤ 10 mm	≤ 10 mm (TBR)	No trim mass control for radial CM
|YCM|	≤ 10 mm	≤ 10 mm (TBR)	
ZCM	Range: 0.8 +/- 0.1 m (from the	Range: 0.65 +/- 0.05 m (from the	Configuration change
	top of the electronics deck)	top of the electronics deck)	
	Knowledge: 20 mm	Knowledge: TBD	
|XCP|	N/A	≤ 10 mm (TBR)	From CM to CP control
|XCP|	N/A	≤ 10 mm (TBR)	

Precession Torque Requirement

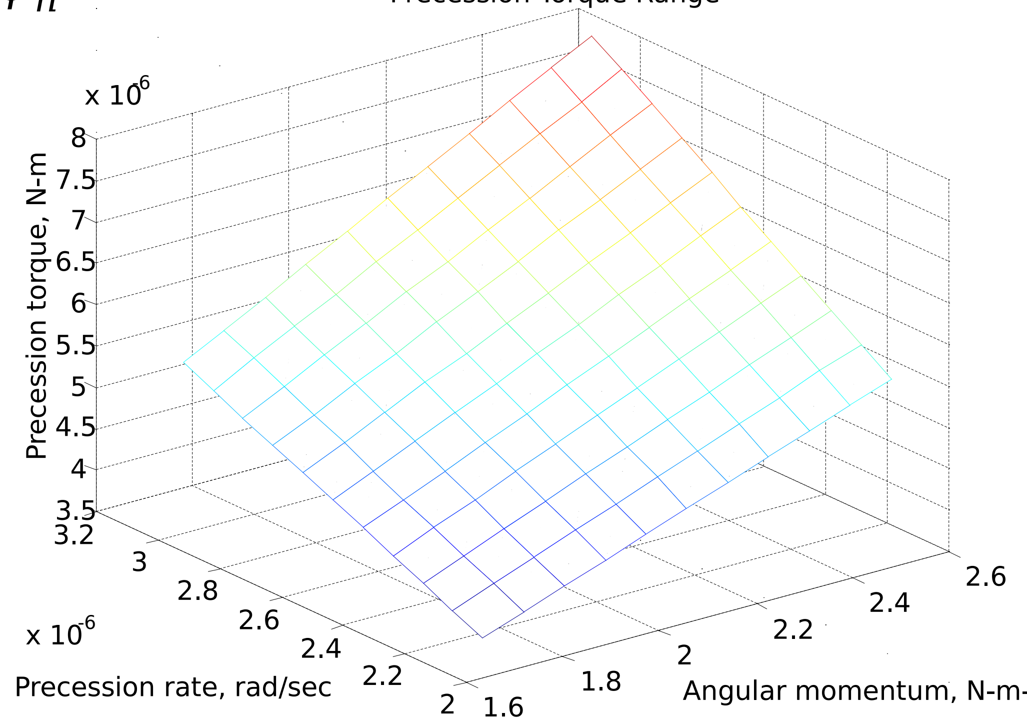
- **Spin axis inertia (kg-m²): 720 ≤ I_s ≤ 880**
- **Spin period (min): 40 ± 4**
- **Angular momentum range (N-m-s): 1.71 ≤ h_s ≤ 2.56**

- **Precession period (days): 20 ± 2**
- **Sun angle (deg): 45 ± 5**
- **Precession rate range (μrad/sec): 2.12 ≤ $\dot{\psi}_h$ ≤ 3.09**



- **Nominal precession torque (μN-m): 5.38**
- **Precession torque range (μN-m):**
  3.64 ≤ T_u ≤ 7.92
- **Average precession torque (μN-m): 5.78**

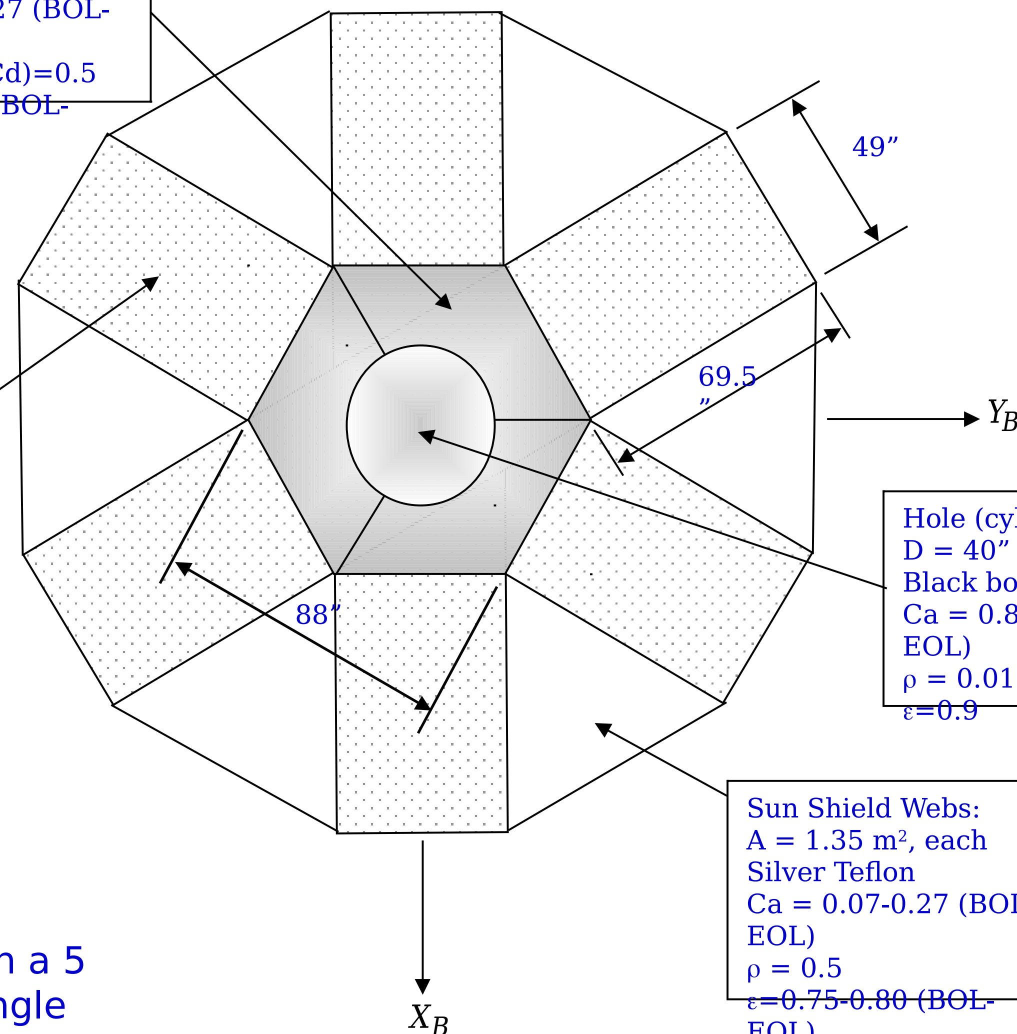
- **Precession torque requirement (μN-m):**
  T_u = 5.8 ± 2.2



Sun Shield Geometry / Optical Properties

Electronics Deck:
A = 1.11 m², each
Silver Teflon
Ca = 0.07-0.27 (BOL-EOL)
ρ = Cs/(Cs+Cd)=0.5
ε=0.75-0.80 (BOL-EOL)

Solar Panels:
A = 2.2 m², each
Covered with 30% solar cells and 70% silver Teflon
Ca = 0.32-0.46, ρ= 0.5
ε=0.78-0.82 (BOL-EOL)



Hole (cylinder):
D = 40” (1.02m)
Black body
Ca = 0.85-0.95 (BOL-EOL)
ρ = 0.01
ε=0.9

Sun Shield Webs:
A = 1.35 m², each
Silver Teflon
Ca = 0.07-0.27 (BOL-EOL)
ρ = 0.5
ε=0.75-0.80 (BOL-EOL)

Dimensions are approximate with a 5 degree sweep angle

Solar Precession Control Requirements (1/2)

- **Accommodate:**
  - **BOL and EOL optical properties**
  - **Sweep angle**
  - **Axial CM offset**
  - **Deployment error**
  - **Thermal radiation torque (blanket vs. no blanket)**
  - **Spin rate variation**
  - **Precession rate variation**
  - **Sun angle variation**
  - **Spin inertia variation**
- **Trim torque range needed for solar precession:**
  - **-0.02 to -11.18 @ 5 deg sweep**
  - **4.90 to -5.87 @ 7 deg sweep**

Sweep angle	5	5	7	7
Absorption	BOL	EOL	BOL	EOL
Specular/diffuse fraction	50% / 50%	50% / 50%	50% / 50%	50% / 50%
Torque (Tu, 1e-6 N-m)				
Solar panels	5.27	7.15	2.35	4.43
Webs	0.41	2.14	-1.89	0.03
Deck	2.62	3.11	2.62	3.11
Hole	1.07	1.04	1.07	1.04
Total solar radiation torque	9.37	13.44	4.15	8.61
Solar panels	-0.59	-0.88	-0.81	-1.23
Webs	-0.09	-0.37	-0.12	-0.50
Deck	0	0	0	0
Hole	0.22	0.25	0.22	0.25
Total thermal radiation torque	-0.46	-1.00	-0.71	-1.48
Solar panels	4.68	6.27	1.54	3.20
Webs	0.32	1.77	-2.01	-0.47
Deck	2.62	3.11	2.62	3.11
Hole	1.29	1.29	1.29	1.29
Total solar and thermal radiation torque	8.91	12.44	3.44	7.13
Precession torque needed	**5.8**	**5.8**	**5.8**	**5.8**
Trim torque needed:				
Solar radiation only case	-3.57	-7.64	1.65	-2.81
Solar + thermal radiation case	-3.11	-6.64	2.36	-1.33
Trim torque needed to accommodate a +/-10% margin for axial CM and delpoyment error:				
Solar radiation only case (min)	-4.51	-8.98	1.24	-3.67
Solar radiation only case (max)	-2.63	-6.30	2.07	-1.95
Solar + thermal radiation case (min)	-4.00	-7.88	2.02	-2.04
Solar + thermal radiation case (max)	-2.22	-5.40	2.70	-0.62
Trim torque needed to accommodate inertia, spin and precession rates, and sun angle variation requirements (+/- 2.2)				
Solar radiation only case (min)	-6.71	-11.18	-0.97	-5.87
Solar radiation only case (max)	-0.43	-4.10	4.27	0.25
Solar + thermal radiation case (min)	-6.20	-10.08	-0.18	-4.24
Solar + thermal radiation case (max)	-0.02	-3.20	4.90	1.58

Solar Precession Control Requirements (2/2)

Sweep angle	7	7	7	7
Absorption	BOL	EOL	BOL	EOL
Specular/diffuse fraction	60% / 40%	40% / 60%	75% / 25%	25% / 75%
Torque (Tu, 1e-6 N-m)				
Solar panels	0.78	5.68	-1.58	7.56
Webs	-3.24	1.09	-5.26	2.68
Deck	2.17	3.47	1.48	4.01
Hole	1.00	1.02	0.98	1.03
Total solar radiation torque	0.71	11.26	-4.38	15.28
Solar panels	-0.81	-1.22	-0.81	-1.22
Webs	-0.12	-0.5	-0.12	-0.50
Deck	0	0	0	0
Hole	0.22	0.25	0.22	0.25
Total thermal radiation torque	-0.71	-1.47	-0.71	-1.47
Solar panels	-0.03	4.46	-2.39	6.34
Webs	-3.36	0.59	-5.38	2.18
Deck	2.17	3.47	1.48	4.01
Hole	1.22	1.27	1.20	1.28
Total solar and thermal radiation torque	0	9.79	-5.09	13.81
Precession torque needed	**5.8**	**5.8**	**5.8**	**5.8**
Trim torque needed:				
Solar radiation only case	5.09	-5.46	10.18	-9.48
Solar + thermal radiation case	5.80	-3.99	10.89	-8.01
Trim torque needed to accommodate a +/-10% margin for axial CM and delployment error:				
Solar radiation only case (min)	5.02	-6.59	10.62	-11.01
Solar radiation only case (max)	5.16	-4.33	9.74	-7.95
Solar + thermal radiation case (min)	5.80	-4.97	11.40	-9.39
Solar + thermal radiation case (max)	5.80	-3.01	10.38	-6.63
Trim torque needed to accommodate inertia, spin and precession rates, and sun angle variation requirements (+/- 2.2)				
Solar radiation only case (min)	2.82	-8.79	8.42	-13.21
Solar radiation only case (max)	7.36	-2.13	11.94	-5.75
Solar + thermal radiation case (min)	3.60	-7.17	9.20	-11.59
Solar + thermal radiation case (max)	8.00	-0.81	12.58	-4.43

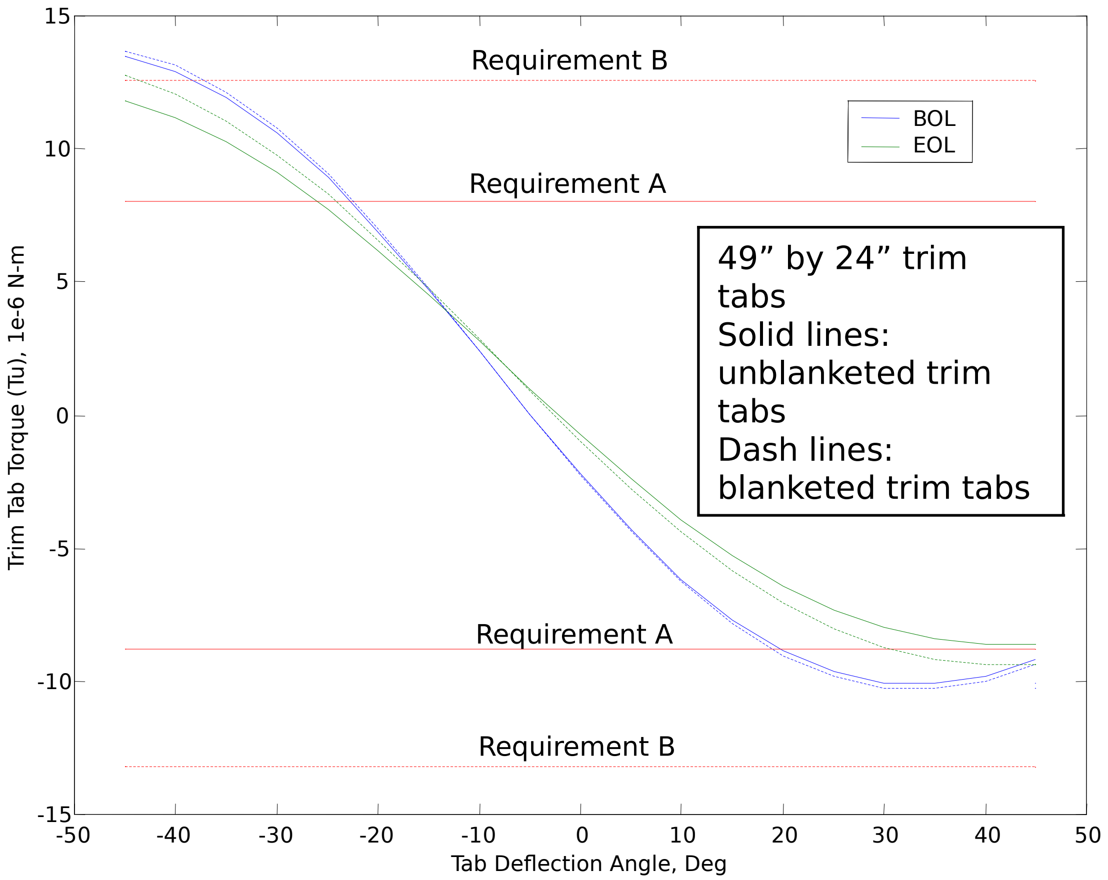
- **Precession torque range required to accommodate specular/diffuse optical property fraction variation of**
  - **60% / 40% (BOL) to 40% / 60% (EOL) (+/-10% knowledge error): 8.00 to -8.79 @ 7 deg sweep angle**
  - **75% / 25% (BOL) to 25% / 75% (EOL) (+/-25% knowledge error): 12.58 to -13.21 @ 7 deg sweep angle**
- **Other obervations:**
  - **Larger torque magnitude for more diffuse surface**
  - **Thermal radiation torque effect is not significant at 7 deg sweep. Blanketing will not affect precession rate control significantly.**

Trim Tab Sizing for Precession Control

- **Control torque requirement (T_u, 10^{-6} N-m):**
  - **Requirement A: +8.00 to -8.79 @ 7 deg sun shield sweep angle, BOL and EOL Ca change, with or without blanketing, and 60% to 40% specular/diffuse reflection ratio change**
  - **Requirement B: +12.58 to -13.21 @ 7 deg sun shield sweep angle, BOL and EOL Ca change, with or without blanketing, and 75% to 25% specular/diffuse reflection ratio change**

- **Trim tab requirement:**
  - **3 total, 120 deg apart**
  - **Silver Teflon**
  - **To satisfy A, 49" by 24" (0.76 m^2) rectangle, longer dimension attached to the panel**
  - **To satisfy B, 49" by 32" (1.01 m^2) rectangle, longer dimension attached to the panel**

- **Assuming specular/diffuse reflection optical property knowledge error of 10% and 7 deg sweep angle, 49" by 24" trim tabs are selected.**



Precession Control Backup Methods

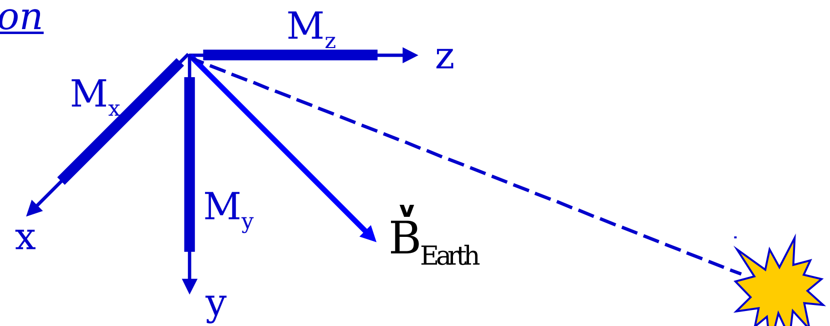
Technical Interchange Meeting
March 20-21, 2001
Naval Research Laboratory

Topics

- Torque rods
- Thermal thrusters
- Thrusters
- Reaction wheels

Magnetic Control Concept

Torque Coil Configuration



- M_x and/or M_y used for active spin control
- M_z used for active nutation control
- Solar pressure used for passive precession control

Feedback Control Laws

$$\left.\begin{aligned} u_x &= k_N I_x(\Omega_{Tx} - \omega_x) \\ u_y &= k_N I_y(\Omega_{Ty} - \omega_y) \end{aligned}\right\} \text{Nutation Control}$$

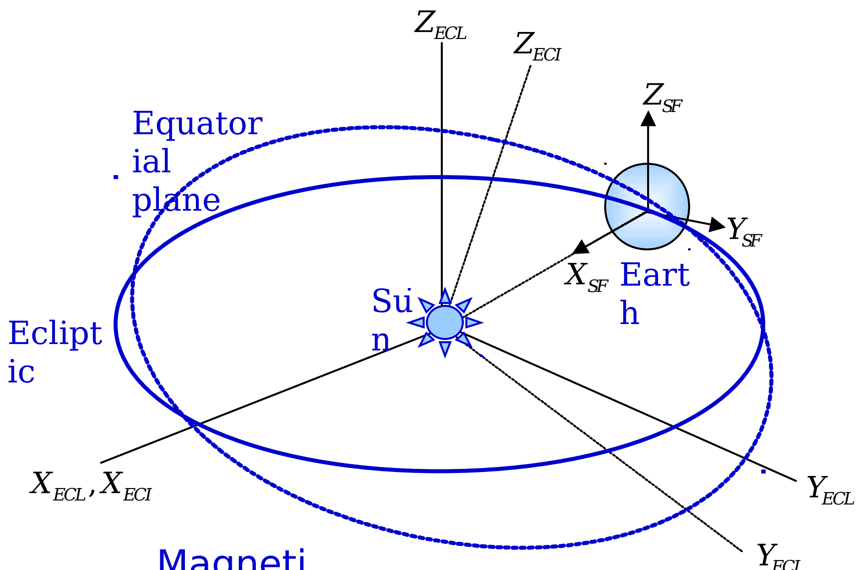
$$\left. u_z = k_S I_z(\Omega_S - \omega_z) \right\} \text{Spin Control}$$

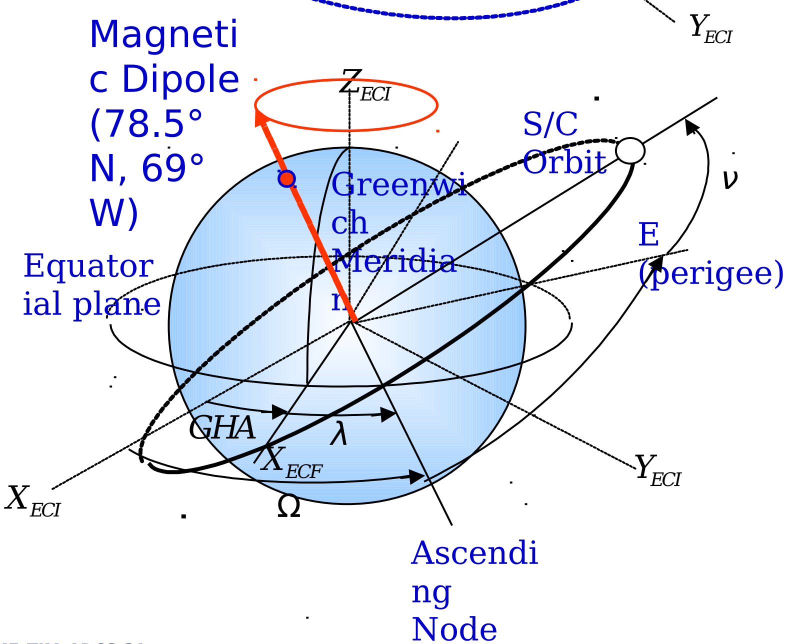
Dipole Logic $(\check{u} = \check{M} \times \check{B})$

$$\left.\begin{aligned} M_x &= \frac{u_z B_y}{B_x^2 + B_y^2} \\ M_y &= -\frac{u_z B_x}{B_x^2 + B_y^2} \end{aligned}\right\} \text{Spin Control}$$

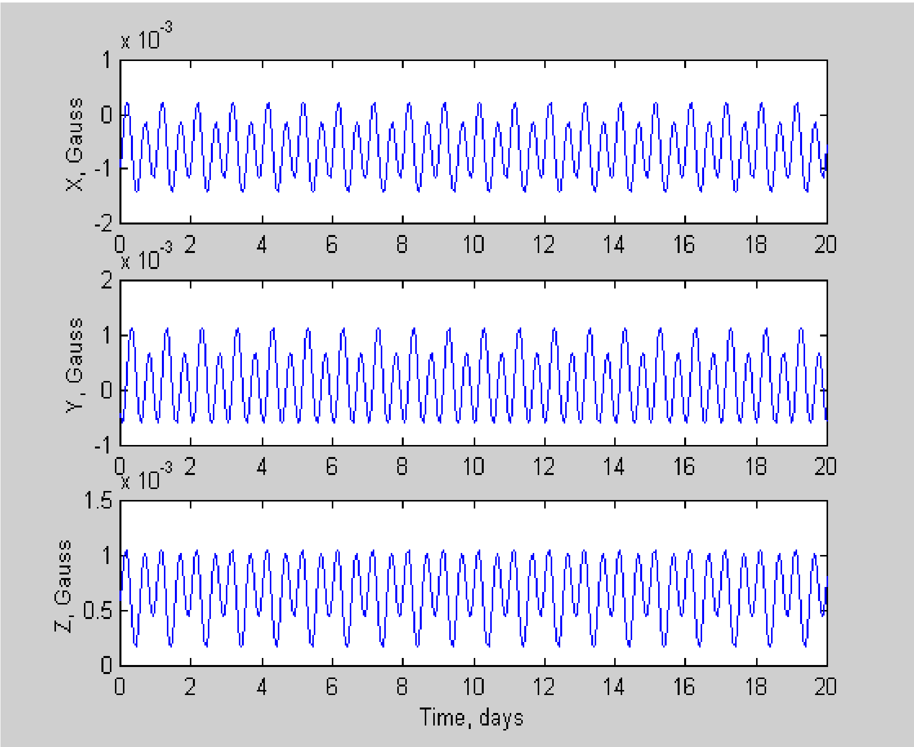
$$\left. M_z = \frac{u_y B_x - u_x B_y}{B_x^2 + B_y^2} \right\} \text{Nutation Control}$$

Earth Magnetic Field Dipole Model at GEO





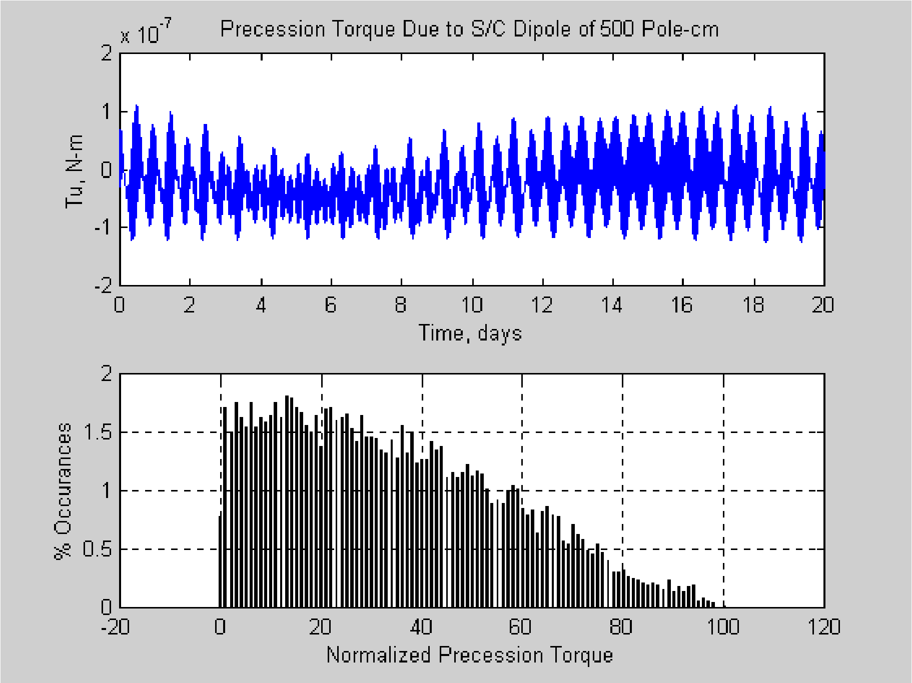
- **Earth Magnetic Field at GEO in ECI (Dipole Model, FAME Orbit)**

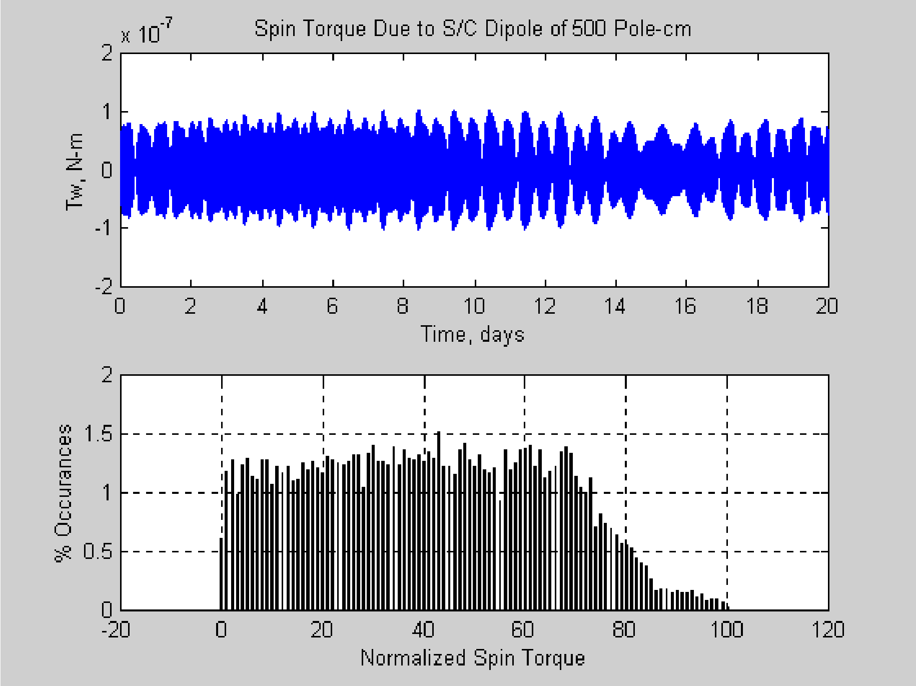


Epoch=July 15, 2004, 01:42:47.000 GMT
GHA=318.95°
Ascending Node=255 °
Inclination=28.7 °
Argument of perigee=0 °
True anomaly=297.02 °

Precession and Spin Control Magnetic Torque Availability

- **Based on precession and spin torque generated by 0.5 Amp-m² (500 pole-cm) dipole moments about S/C X, Y, and Z axes.**
- **20 day (one precession period) on FAME orbit (GEO, 28.7 deg inclination)**





Percentage of peak torque	Time available for precession control (%)	Time available for spin control (%)
>10	83.0	87.5
>50	24.8	36.9
>75	4.8	7.1
>90	0.9	1.1

Impact of Magnetic Torque Availability on Torque Rod Sizing

- **Precession Control Torque Rod**

Precession Torque Required (10^{-6} N-m)	Required Torque Rod Capability (Amp-m^2)		
	90% Availability	75% Availability	50% Availability
5	333.8	133.5	64.6
10	667.5	267.0	129.2
15	1001.3	400.5	193.8

- **Spin Control Torque Rod**

Spin Torque Required (10^{-6} N-m)	Required Torque Rod Capability (Amp-m^2)		
	90% Availability	75% Availability	50% Availability
0.1	6.1	2.3	1.2
0.5	30.4	11.6	6.1
1	60.7	23.1	12.1

- **Torque Rod Specification**

Torque Rod Capability (Amp-m^2)	Ithaco TORQROD Specification		
	Unit Size (length x diameter, in)	Unit Weight (lb)	Unit Power (W)
15 (SRR Baseline)	15.0 x 0.7	1.0	20.4
75	25.1 x 1.1	3.75	12.4
130	16.2 x 2.0	9.8	13.5
290	36.0 x 1.3	9.6	32.8
550	50.3 x 1.3	17.0	25.9
950	55.1 x 1.6	30.0	34.0

Magnetic Control: Summary

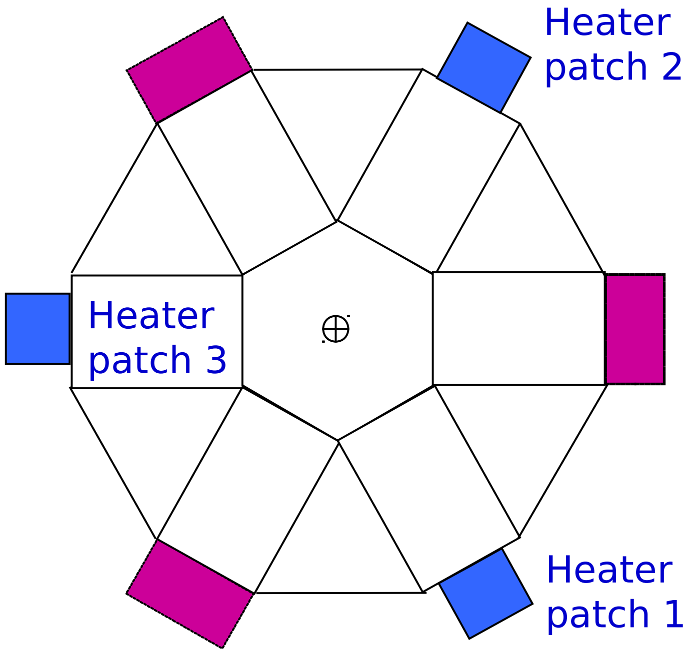
- Magnetic control is employed to augment (not to replace) solar radiation pressure control to allow a wider margin for optical property, geometry, and deployment errors of the sun shield.
- Earth magnetic field orientation makes precession control (directed torque in the inertial frame) more difficult to achieve than the spin control (body fixed torque).
- Availability requirement of magnetic control (e.g., 90%, 75%) will be a major factor in determining the size of torque rods.
- Torque required for precession control is in general an order of magnitude larger than the spin control torque.
- Size, weight, and power of a torque rod are not directly proportional to the torque rod capability (Amp-m^2), allowing accommodation of higher capability manageable.
- Complete performance simulation for magnetic control will be conducted.

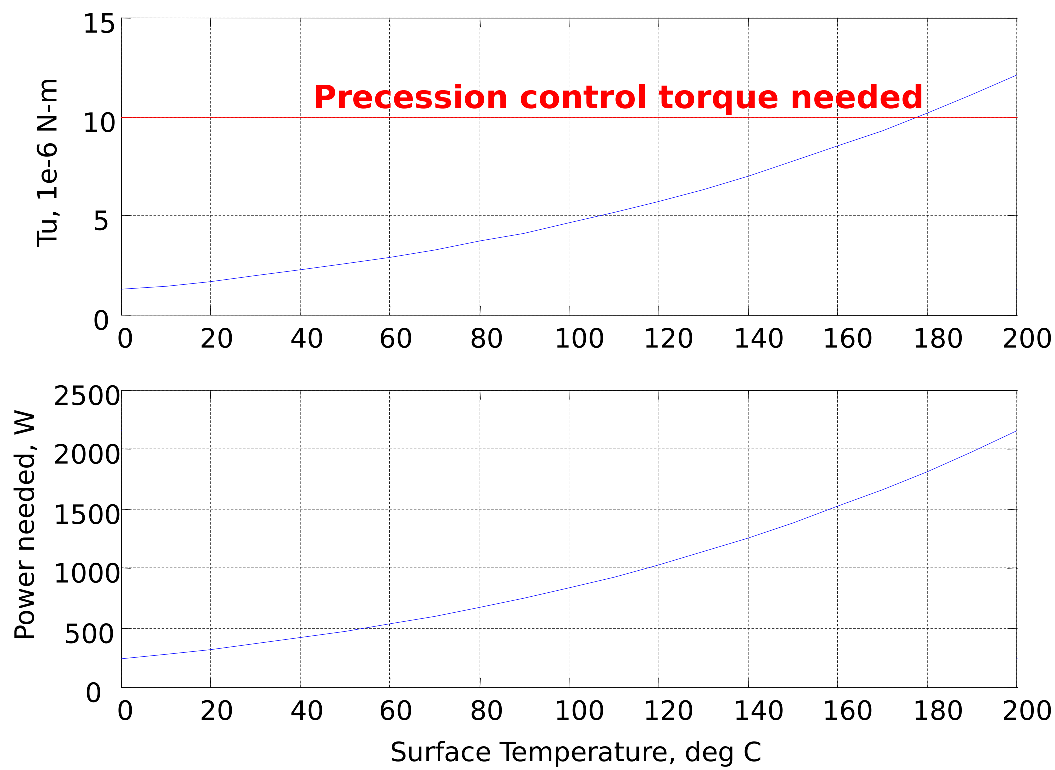
Precession Rate Control Thermal Thruster (1/2)

United States Naval Observatory

LOCKHEED MARTIN

- **Assumptions:**
  - **Movable trim tabs are replaced with fixed heater patches for precession control**
  - **Area: 49 inches by 24 inches**
  - **Emissivity: 0.8**
  - **Tab shade side temperature: -130°C**
  - **Moment arm from the spin axis: 3.2 m (125.5 inches)**





- **Estimated power consumption:**
  - **1800W maximum per patch @ 180°C**

Precession Rate Control Thermal Thruster (2/2)

- **Operation:**
  - **Modulate the heater temperature at spin rate to provide continuous, inertially-directed torque of a given magnitude**

- **Pros:**
  - **No mechanism / motor involved**
  - **Light weight**

- **Cons:**
  - **Large power consumption by the heater**
  - **Continuous temperature modulation for precession control**

Thrusters and Reaction Wheels

- Thrusters for precession control
  - Continuous precession control is not achievable with Hydrazine thrusters.
  - Impact of the intermittent (stop-and-go) precession control on instrument performance needs to be quantified.
- Reaction wheels for precession control
  - Torque resolution is too large (>> 5 μN-m).
  - A source of jitter.

Nutation Damper Trades

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March 20-21, 2001
Naval Research Laboratory

Nutation Damper Trade: Status

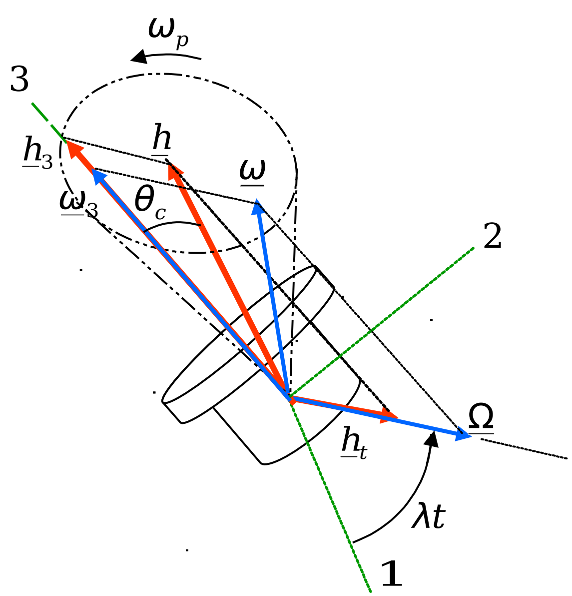
- Active damping using electromagnetic torquers (EMT's) has been selected as a baseline
  - SRR study indicates a 10 as (1σ) nutation angle control capability
  - Further study is needed with updated mass property and requirements.
- Passive damping from fuel slosh and structural damping will be quantified as needed data becomes available.
- Mechanical damper is still being considered.

Magnetic Control Torque Requirement for Nutation Damping

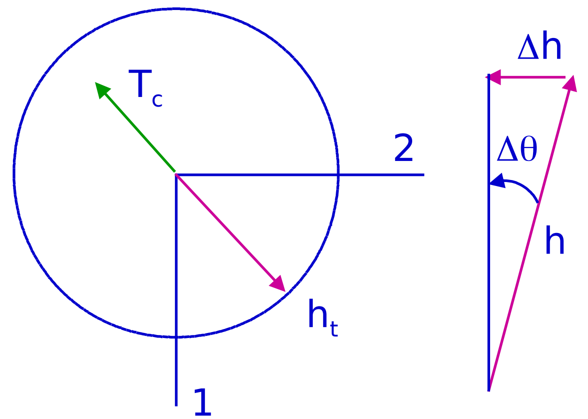
- **Nutation (cone) angle**

$$\theta_c \cong \tan\theta_c = \frac{h_t}{h_3} = \frac{I_t\Omega}{I_s\omega_3} = \frac{I_t\Omega}{I_s\omega_0}$$

  - **Requirement: $\underline{+}$10as (TBR)**



- **Nutation control torque requirement**



$h = I_s\omega_s$

$\Delta\theta = \Delta h / h$

$T_c = \Delta h / \Delta t$

Nutation Angle Change ($\Delta\theta$, as)	Required Torque (10^{-6} N-m)		
	Δt=10 min	Δt=20 min	Δt=40 min
10	0.17	0.08	0.04
100	1.7	0.85	0.42
200	3.4	1.7	0.85

- **Nutation control torque rod**

Nutation Torque Required (10^{-6} N-m)	Required Torque Rod Capability (Amp-m^2)		
	90% Availability	75% Availability	50% Availability
0.1	6.7	2.7	1.3
1	66.8	26.7	12.9

Magnetic Control Hardware

Item	Quantity	Capability	Unit Size	Unit Mass	Unit Power
Torque Coil (Ithaco TR10CFR)	3	(+/-) 15 amp-m^2	38 x 5 x 4 cm	0.454 kg	1.6 W
3-Axis Magnetometer (Ithaco IM-103)	1	(+/-) 120 mG with a resolution of 60 μG [1]	16 x 4 x 4 cm	0.227 kg	1 W
			Total	1.6 kg	5.8 W

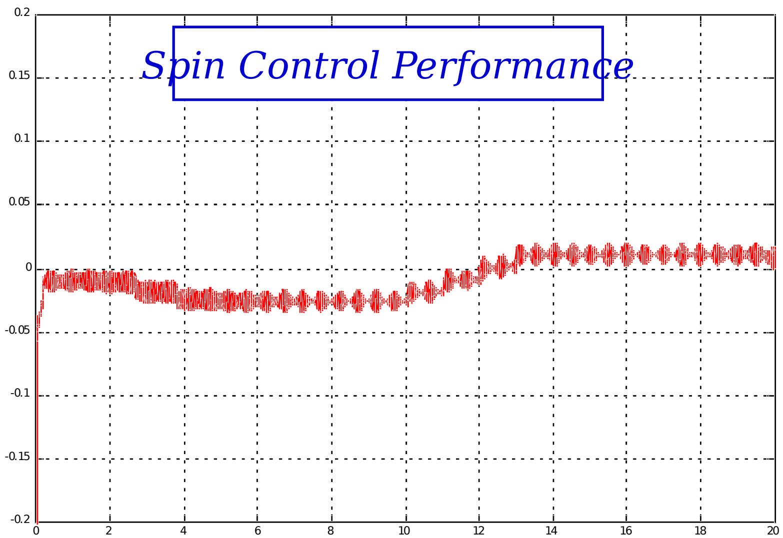
Note (1): Resolution obtained using a 12-bit A/D converter over a +/- 1 volt range

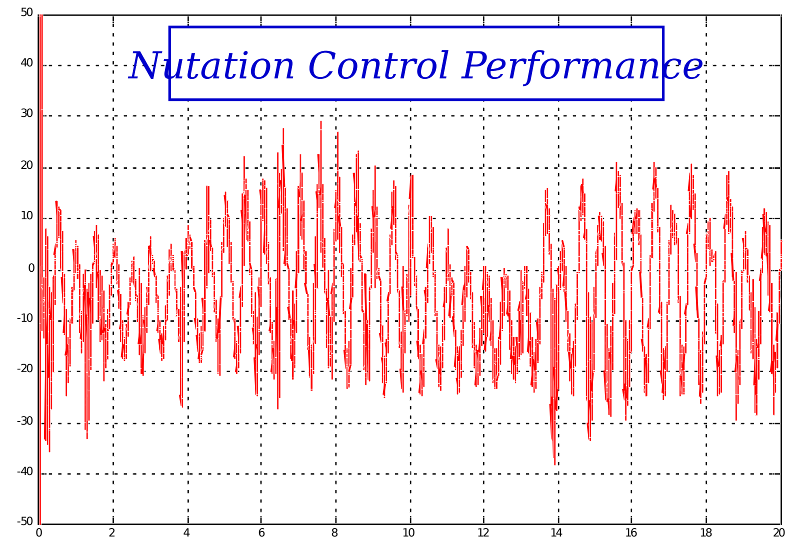
Magnetic Control Simulation Results

Based on SRR Mass Property

Simulation includes:

- ✔ Geosynchronous orbit dynamics and low-spin attitude dynamics
- ✔ High-order magnetic field model
- ✔ Ideal Sun precession control
- ✔ Gravity gradient disturbances
- ✔ Bias S/C dipole, $M_{bias} = 0.5$ amp-m²
- ✔ Magnetometer random noise and bias errors
- ✔ High-pass magnetometer filter to remove magnetometer bias
- ✔ Torque coil shut-off during magnetometer sensing
- ✔ Simple On/Off dipole logic using small coils ($M_x = M_y = M_z = +/- 15$ amp
- ✔ Non-ideal inertia matrix, $I_{S/C} = \begin{bmatrix} 360 & 3 & 0 \\ 3 & 370 & 0 \\ 0 & 0 & 400 \end{bmatrix}$ kg-m²





ACS Propellant & Thruster Configuration

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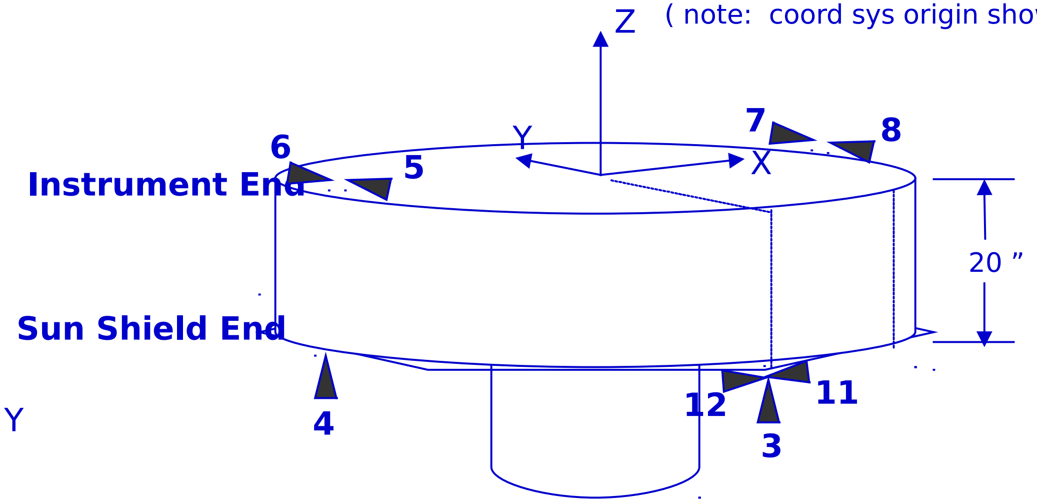
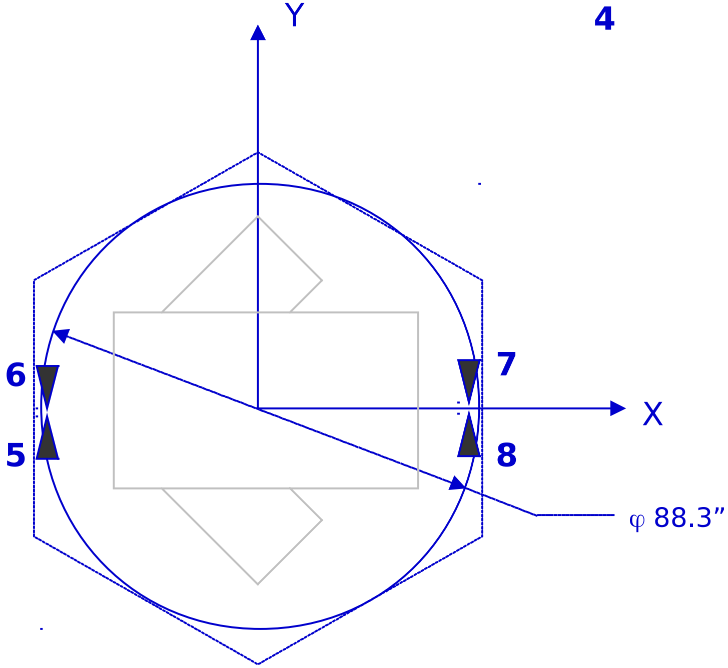
Thruster Layout

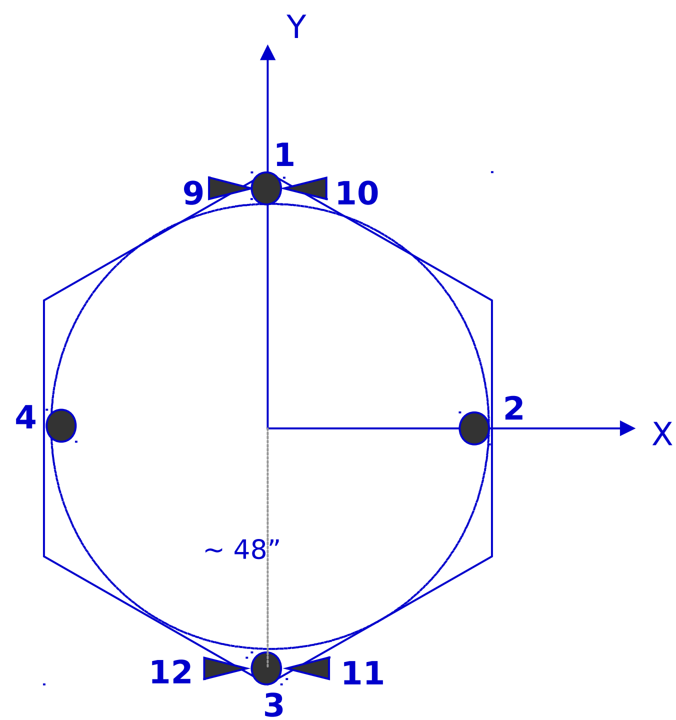


Thruster sizing
1-4: 5 lbf
5-8: .2 lbf or 1 lbf (TBR)
9-12: 1 lbf



Instrument End

ID	Thrust directio x	y	z
1	0	0	1
2	0	0	1
3	0	0	1
4	0	0	1
5	0	1	0
6	0	-1	0
7	0	-1	0
8	0	1	0
9	1	0	0
10	-1	0	0
11	-1	0	0
12	1	0	0



Sun Shield End

ACS Propellant Budget

	Configuration	Mprop (kg)	Mprop (lbm)
1	**Flight Vehicle, Stowed, Wet AKM**	**19.0**	**41.9**
2	**Flight Vehicle, Stowed, Dry AKM**	**9.4**	**20.8**
3	**Spacecraft, Stowed, Wet**	**0.3**	**0.6**
4	**Spacecraft, Deployed, Wet**	**6.0**	**13.3**
	total	**34.7**	**76.6**

1 Flight Vehicle, Stowed, Wet AKM

Null tip-off from Delta 3rd stage	0.13	
Inertial pointing (3-axis limit cycle)	0.40	
Slew maneuvers	0.18	
SHM spin-up/down	0.10	
AKM spin-up	2.23	
Active Nutation Control	15.60	
Spin axis precession	0.35	
subtotal	19.0	kg

3 Spacecraft, Stowed, Wet

Slew maneuver	0.03	
Inertial pointing (3-axis limit cycle)	0.24	
subtotal	0.27	kg

2 Flight Vehicle, Stowed, Dry AKM

ANC following AKM firing	3.45	
Post-AKM spin-down	1.95	
Slew maneuvers	1.00	
Inertial ptg during ACS Delta-V	0.46	
Inertial pointing (3-axis limit cycle)	2.59	
subtotal	9.4	kg

4 Spacecraft, Deployed, Wet

Slew maneuvers	1.74	
Inertial pointing (3-axis limit cycle)	2.15	
Inertial ptg during ACS Delta-V	0.60	
SHM spin-up/down	1.56	
subtotal	6.04	kg

Center Of Mass Location

Stowed w/AKM

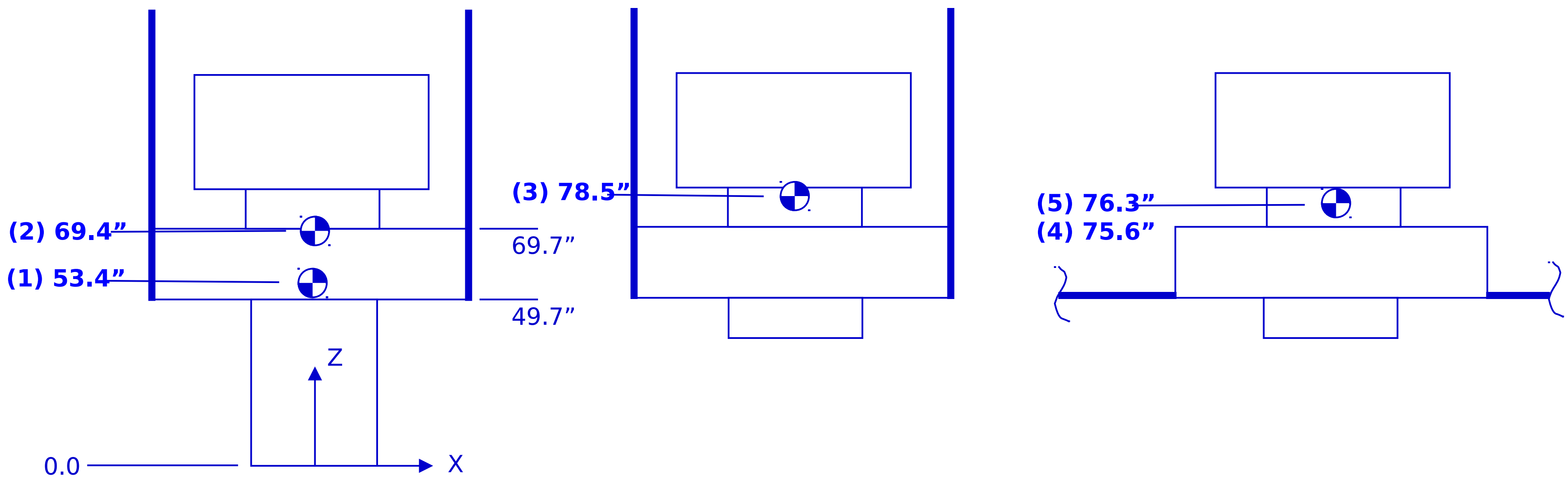
(1) Flight Vehicle, Stowed, Wet AKM
(2) Flight Vehicle, Stowed, Dry AKM

Stowed w/o AKM

(3) Flight Vehicle, Stowed, Wet

Deployed

(4) Flight Vehicle, Deployed, Wet
(5) Flight Vehicle, Deployed, Dry



source: 3/5/01 Mass Props Report, 3rd Design Iteration

Thruster/Propellant Issues

- Still working both thruster layout and ACS propellant budget
  - ANC design very preliminary, need to study further
    - Impact on thruster selection (#1 - #4)
    - Impact on propellant estimate
    - Need to study sloshing and compute energy dissipation
      - Near term alternative is to gain confidence in ANC propellant margin
  - Need to update timelines for up to date on-orbit maneuver sequence
    - Impact on propellant estimate
  - Thruster use as backup to solar precession (not currently included)
    - Impact on thruster selection (#5 - #8)
    - Impact on propellant estimate

Trim Areas and CP-to-CM Balancing

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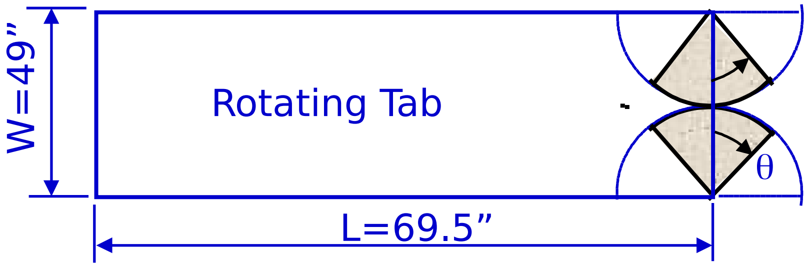
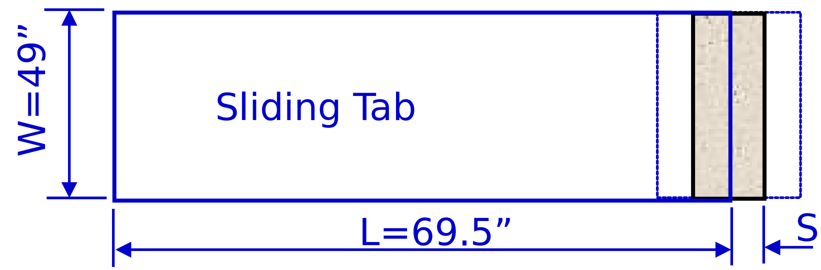
Area Control Tab Sizing for CP Control (1/2)

- **Area Control Tab Options**

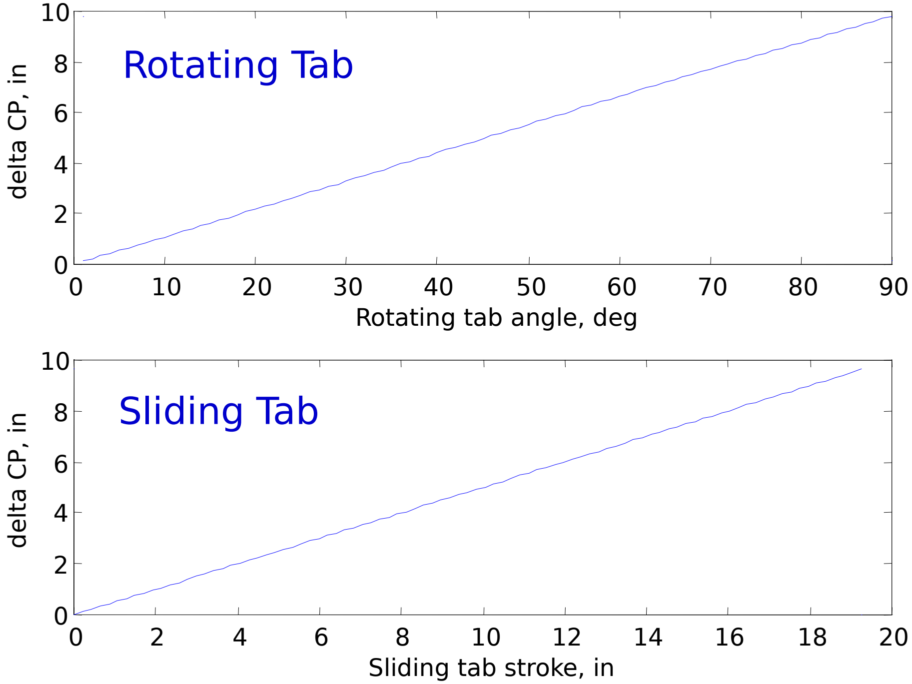




Function	Rotating Tabs (a pair as a unit)	Sliding Tab
Area adjustment	[illegible]	[illegible]
Corresponding CP change of the tab	[illegible]	[illegible]
Corresponding CP change of the panel	$\dfrac{\dfrac{WL^2}{2} + \dfrac{W^2\theta}{4}\left(L + \dfrac{W(1-\cos\theta)}{3\theta}\right)}{WL + \dfrac{W^2\theta}{4}} - \dfrac{L}{2}$	[illegible]
Pros and Cons	Pros: Reliable operation Cons: Control area limited	Pros: Control area unlimited Cons: Sliding tracks tend to bind

Area Control Tab Sizing for CP Control (2/2)

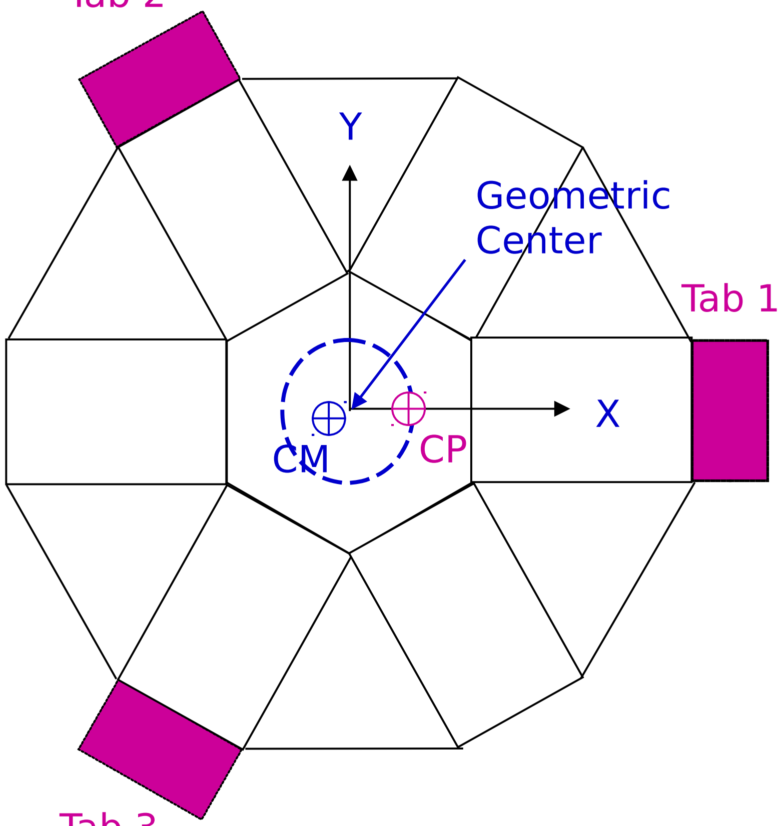
- **Panel CP change capability of rotating and sliding tabs are about the same with the same tab area.**

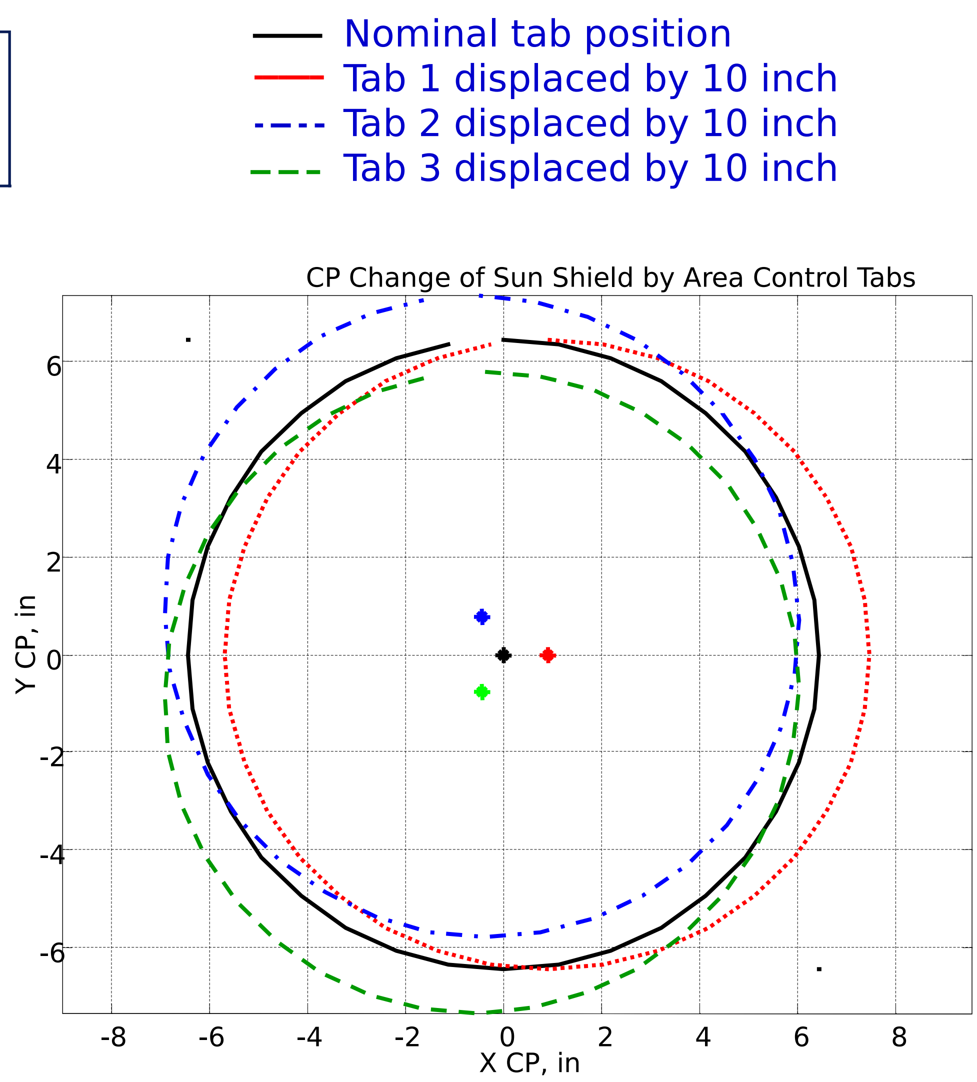


- **Rotating tab angle of 0.1 deg change produces about 1/100 inch (0.25mm) panel CP change.**

Sun Shield CP Change by Area Control Tabs (1/2)

- Only area control tabs are shown
- 7 deg sweep angle
- Sun vector in X-Z plane, 45 deg off Z axis



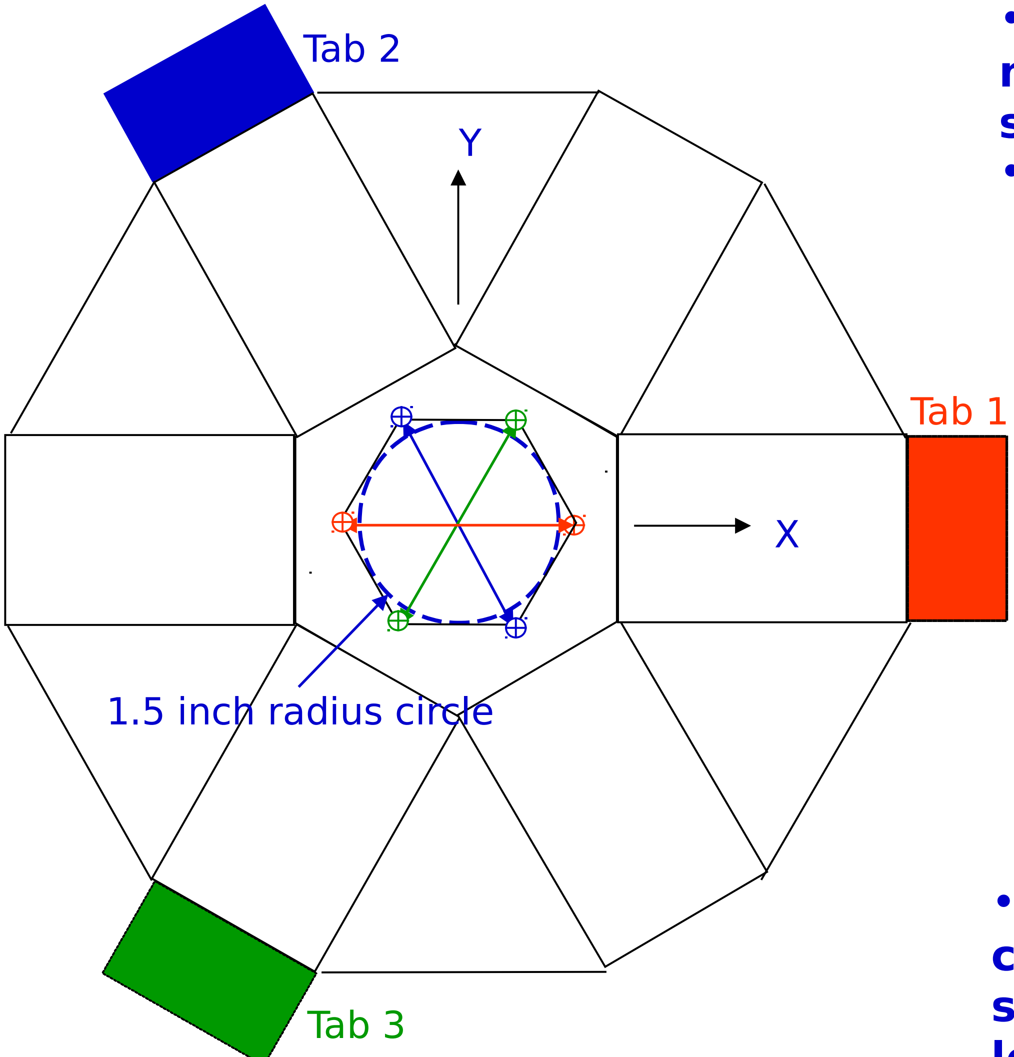


Sun Shield CP Change by Area Control Tabs (2/2)

- Radius of the CP circle is proportional to the sweep angle.
- Area tabs control the location of the CP circle center.
- Optical property variations and deployment/geometry errors in the sun shield will produce distortion to the CP circle. Area tabs cannot change the shape of the CP circle unless they are allowed to be modulated at the spin rate.

Range of CP Change by Area Control Tabs

- Entire sun shield CP change by the area tabs.



- +/- 10 inch stroke single tab motion produces +/- 0.9 inch sun shield CP change
- CP control examples:

Tab Stroke (inch)			CP Change (inch)		
Tab 1	Tab 2	Tab3	XCP	YCP	CP distance
10	0	0	0.89	0	0.89
0	10	0	-0.45	0.77	0.89
0	0	10	-0.45	-0.77	0.89
-10	0	0	-0.9	0	0.89
0	-10	0	0.45	-0.77	0.89
0	0	-10	0.45	0.77	0.89
10	10	0	0.45	0.77	0.89
10	0	10	0.45	-0.77	0.89
10	-10	10	0.89	-1.54	1.78
10	-10	0	1.34	-0.77	1.54

- By moving 3 tabs in coordination, CP of the sun shield can be placed at any location within a 1.5 inch radius circle about the spin

Precession Rate Control by Area Control Tabs

- **Area tabs will provide additional precession rate control capability when adjusted in unison.**

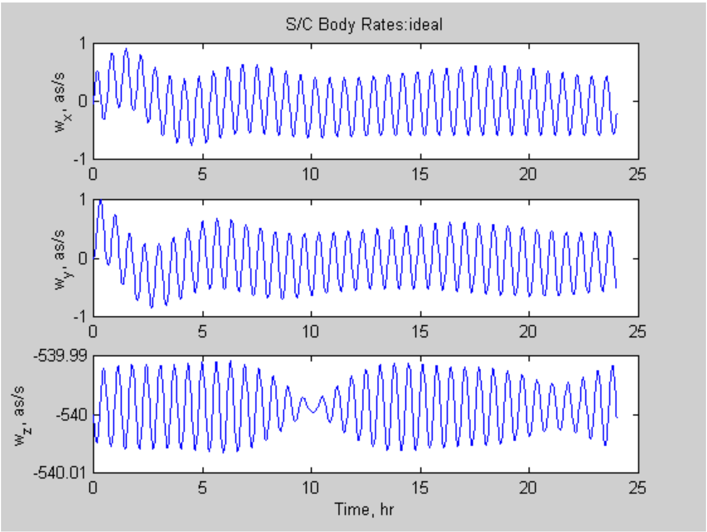
Sweep angle (deg)	7	7	7	7	7	7
Absorption	BOL	BOL	BOL	EOL	EOL	EOL
Specular/diffuse fraction (%)	60/40	60/40	60/40	40/60	40/60	40/60
Area tab extension (in)	0	10	20	0	10	20
Solar radiation torque (Tu, 1e-6 N-m)	0	-0.80	-1.73	0	-0.27	-0.66
Solar and thermal radiation torque (Tu, 1e-6 N-m)	0	-0.82	-1.77	0	-0.35	-0.83

- **Area tabs help reduce the solar radiation precession torque when extended to its nominal position of 10 inches.**

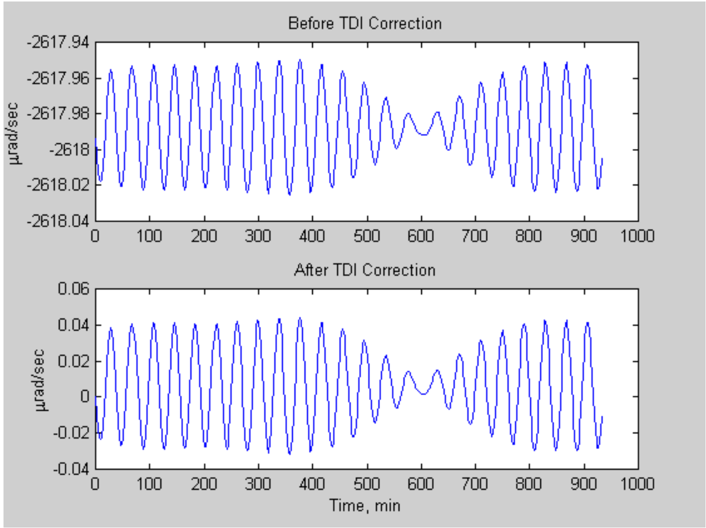
Ideal Model Performance

With Gravity Gradient and Magnetic Torque

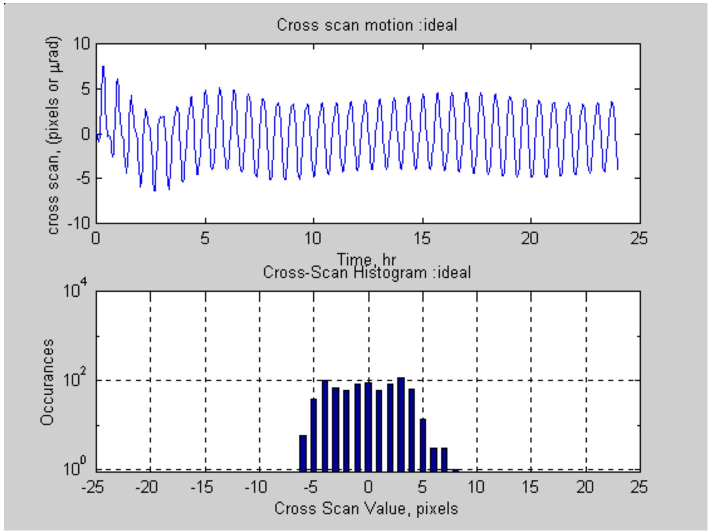
- **Body rates**

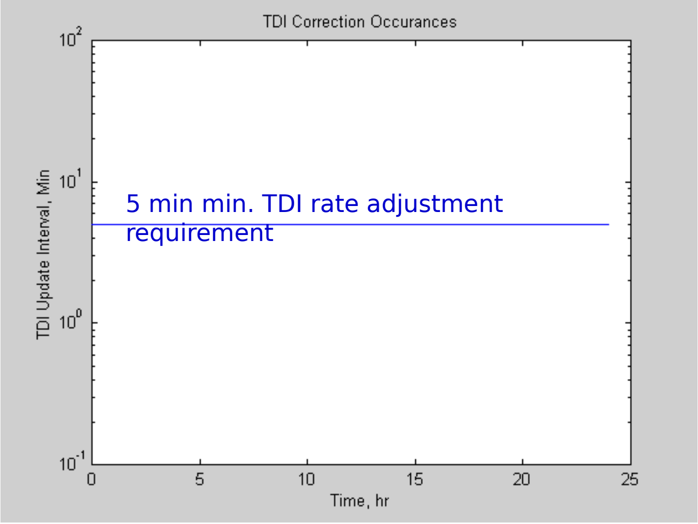


- **TDI correction for spin rate**



- **Cross-scan performance**

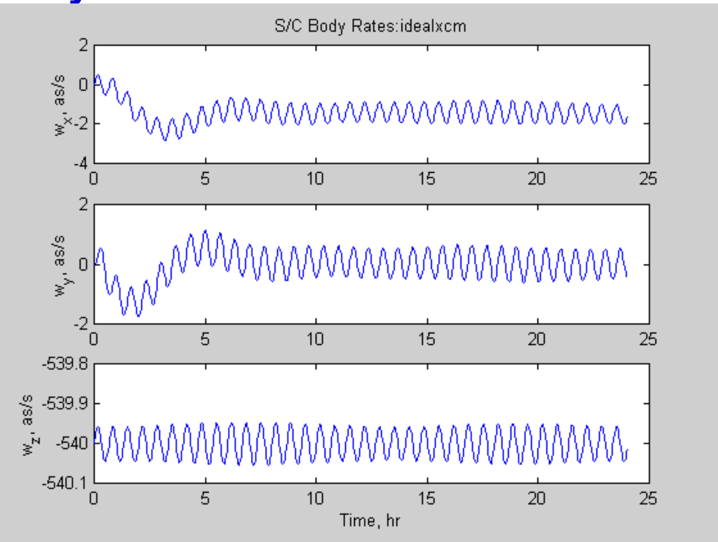




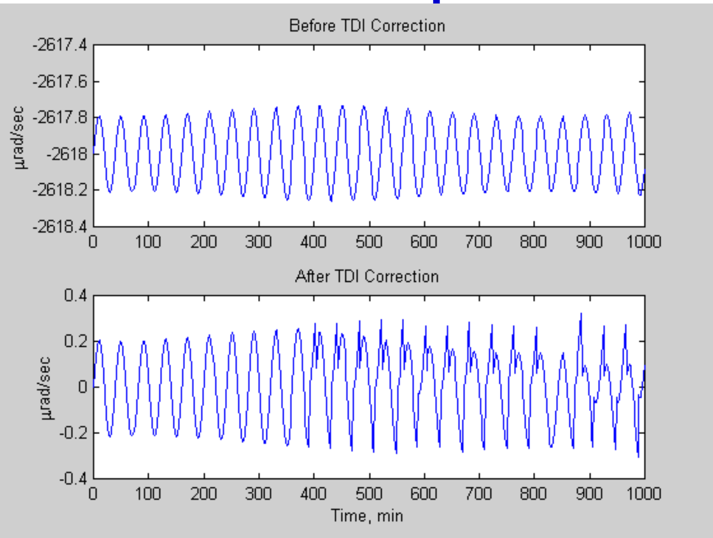
Performance with CM Offset

0.5 Inch CM Offset Along X Axis

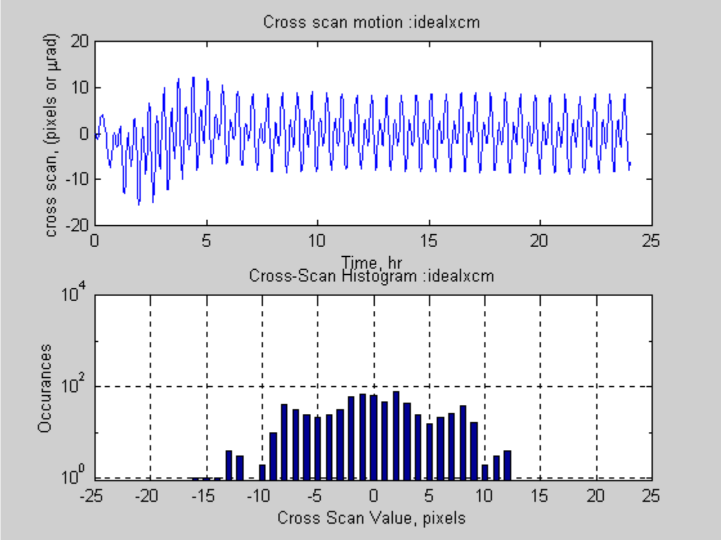
- **Body rates**

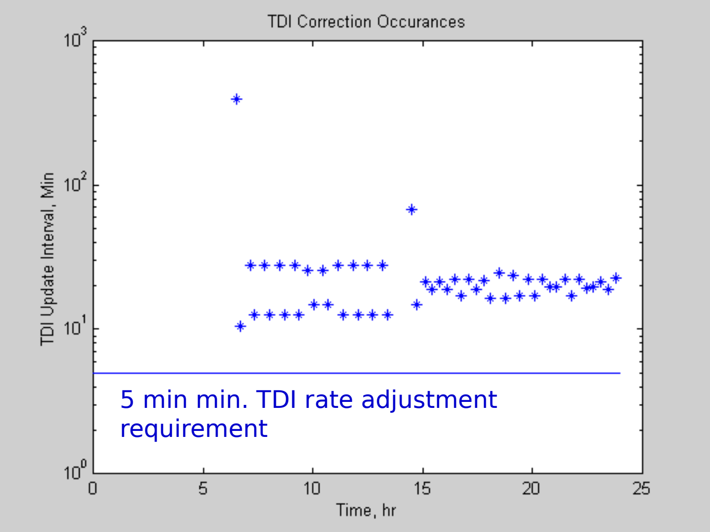


- **TDI correction for spin rate**



- **Cross-scan performance**





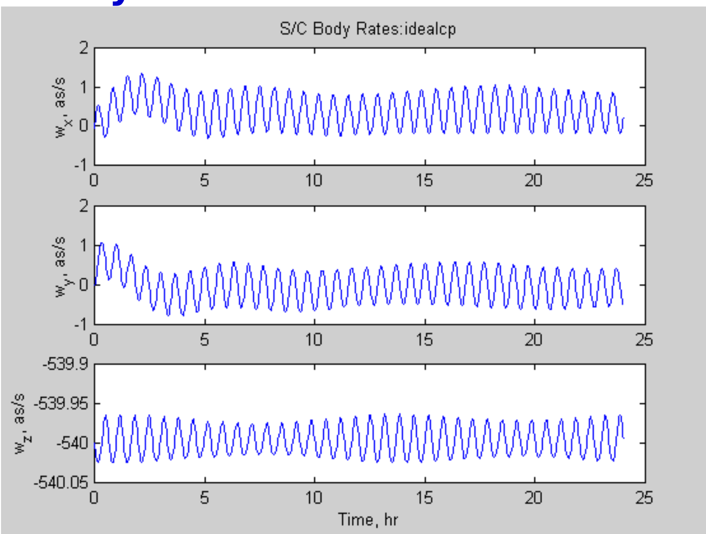
Performance with CP Correction

United States Naval Observatory

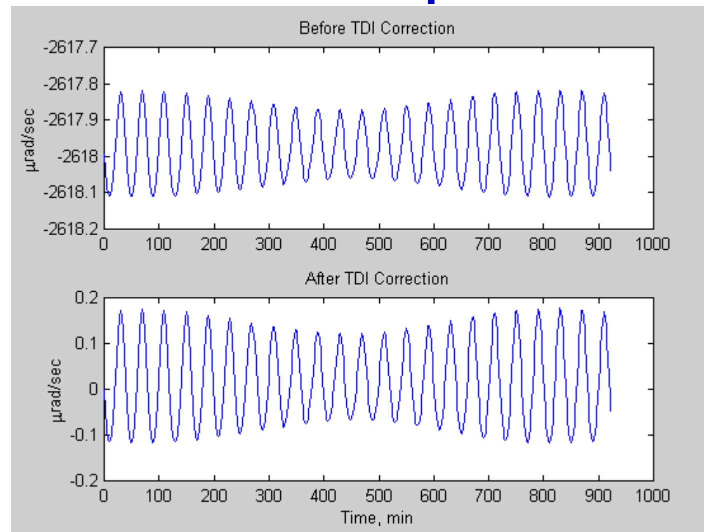
LOCKHEED MARTIN

5 inch Area Tab 1 Extension for CP Correction

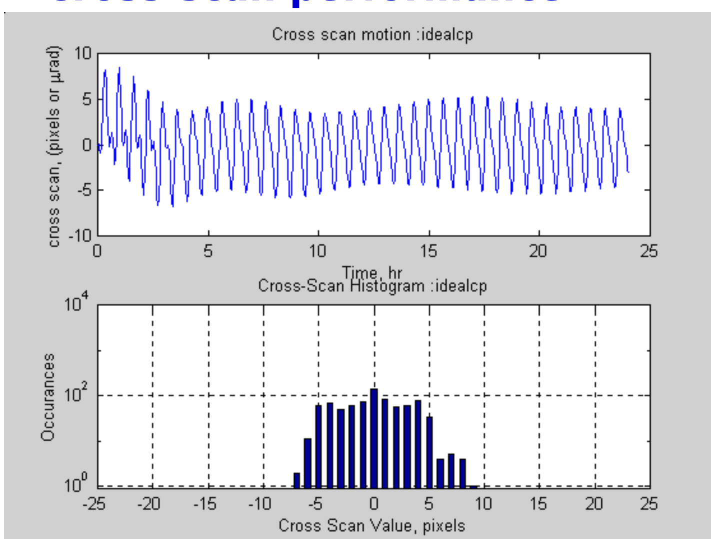
- **Body rates**

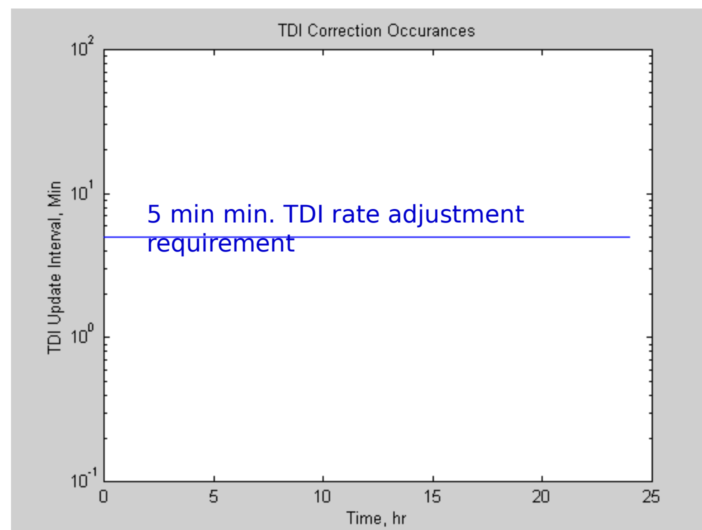


- **TDI correction for spin rate**



- **Cross-scan performance**





Spin Rate Control Methods

Technical Interchange Meeting
March 20-21, 2001
Naval Research Laboratory

Spin Rate Control Requirements

- **Requirements for Stellar Mapping**

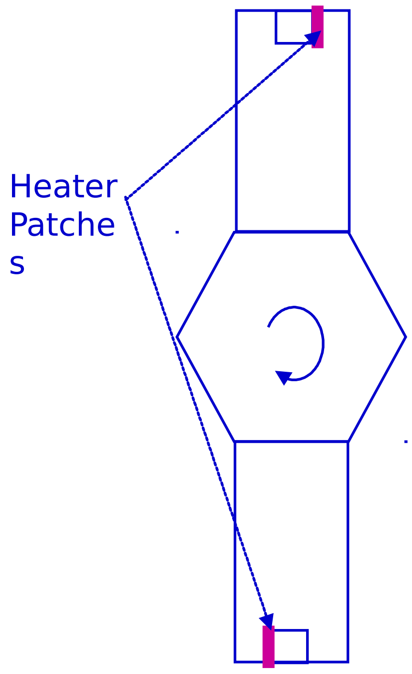
Spin Control Function	Torque Needed, |Tz|	Torque Impulse Needed	Remarks
Spin up/down to 40 +/- 4 min period	> 6e-4 N-m	< 0.05 N-m-sec	60 min max. time to spin +/-1 min spin period control accuracy
Bias spin rate error control	< 3.5e-7 N-m (continuous only)	< 1e-4 N-m-sec	+/-0.131 μrad/sec over 300 sec variation +/-0.1 deg sun shield roll angle deployment error
Cyclic spin rate error control	< 3.5e-7 N-m (TBR) at spin, orbital, and precession (and their multiple) periods	< 1e-4 N-m-sec (TBR)	+/-0.131 μrad/sec over 300 sec variation Deployment, geometry, optical property errors Gravity gradient torque Magnetic torque

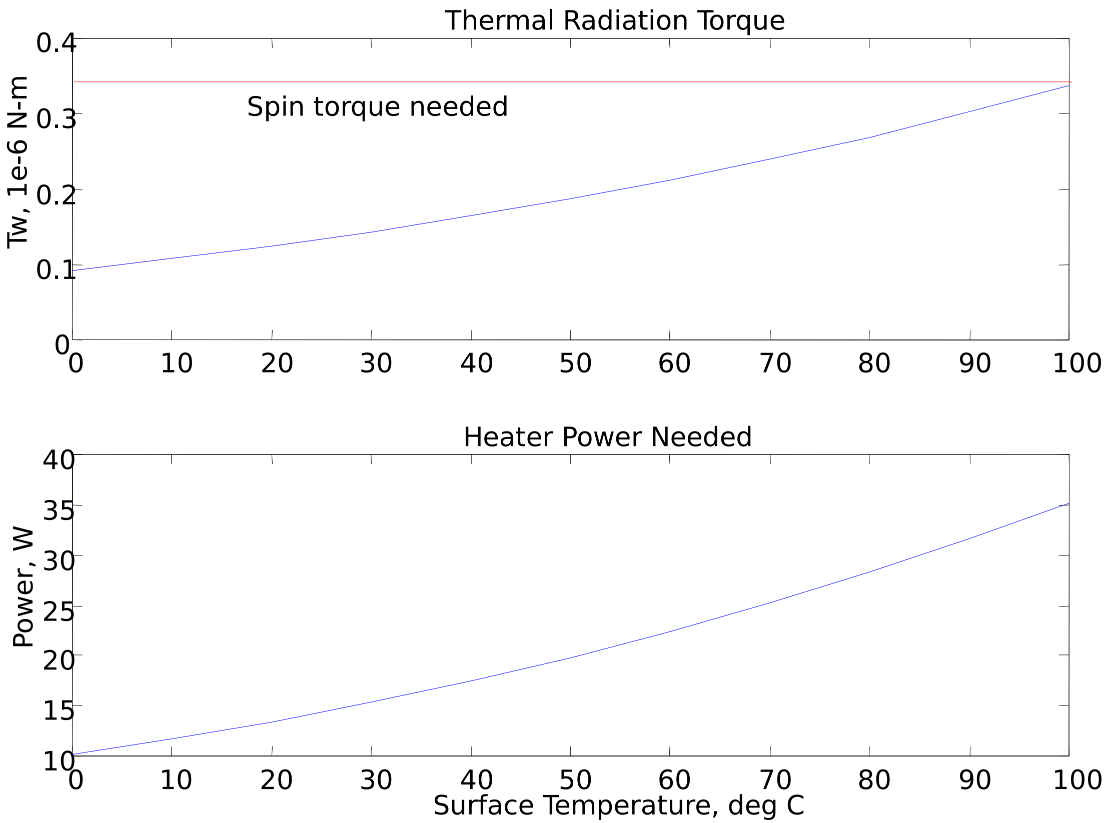
Spin Rate Control Options

Spin Control Function	Control Options				Best Selection
	Thrusters (44" moment arm, a pair)	Torque Rod	"Roll" Trim Tabs (120" moment arm, a pair)	Heater Patches (109" moment arm, a pair)	
Spin up/down to 40 +/- 4 min period	1 N thruster with 50 ms min. on-time 4	>35,000 Amp-m^2 capacity required X	Insufficient control authority X	Insufficient control authority X	Thruster
Bias spin rate error control	Control torque too large X	>3.5 Amp-m^2 capacity required 4	$0.02m^2$ area at 45 deg deflection (bias setting) 4	10" by 5" heater patch at 100 °C (continuously on) 4	Heater patch
Harmonic spin rate error control	Control torque too large X	>3.5 Amp-m^2 capacity required 4	$0.02m^2$ area at 45 deg deflection (modulated at spin rate) X	10" by 5" heater patch at 100 °C (modulated at spin rate) X	Torque rod
Pros and Cons	Pros: existing for other functions as well Cons: too coarse for fine adjustment	Pros: flexiblilty in control torque generation, no moving parts Cons: torque generation depends on earth mag. field	Pros: minimal power consumption Cons: weight penalty, mechanism complexity and cost	Pros: No moving parts Cons: continuous power consumption	

Spin Rate Control Thermal Thruster

- **Assumptions:**
  - **A pair of heater patches located at each end of panel**
  - **Area: 10 inches by 5 inches**
  - **Emissivity: 0.8**
  - **Solar panel shade side temperature: -130°C**
  - **Moment arm from the spin axis: 2.76 m (109 inches)**





- **Power consumption:**
  - **70W maximum per pair @ 100°C**

On-Orbit Spin Balancing and CM Estimatio

Technical Interchange Meeting
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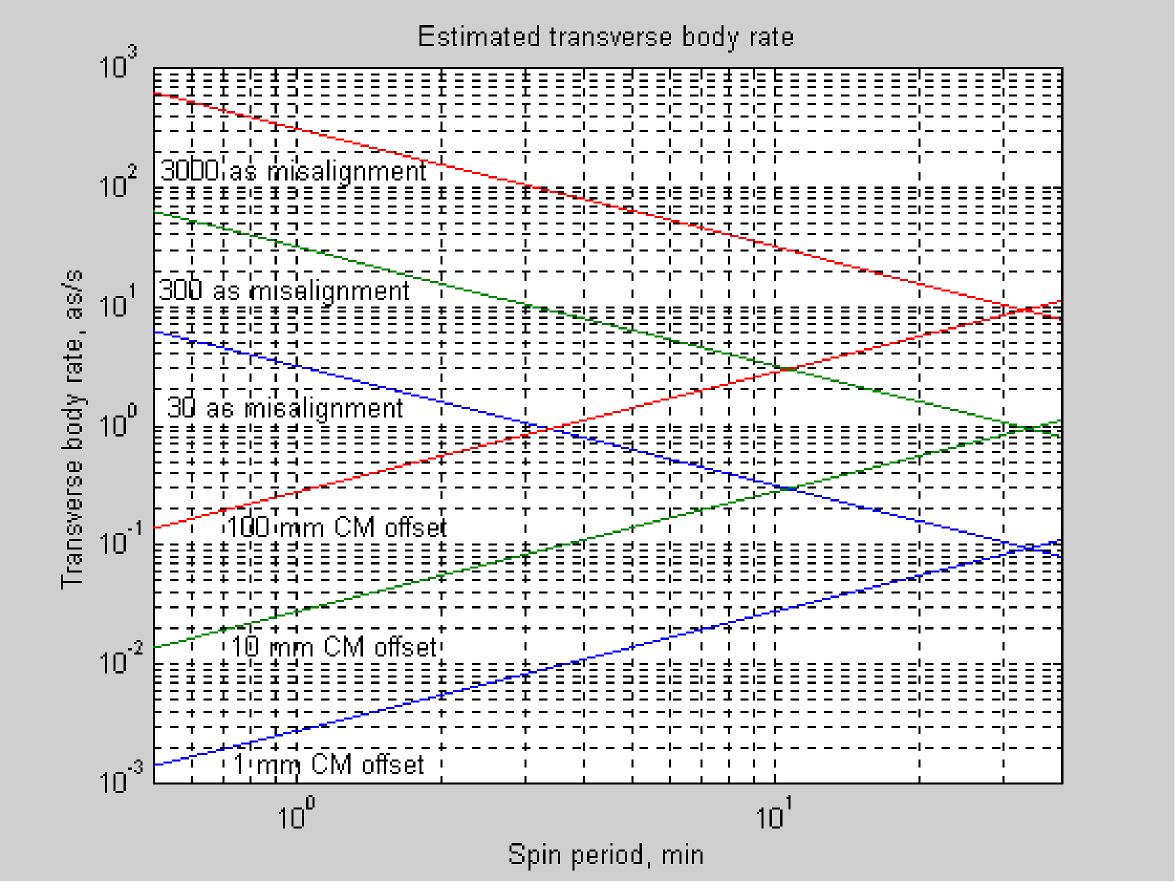
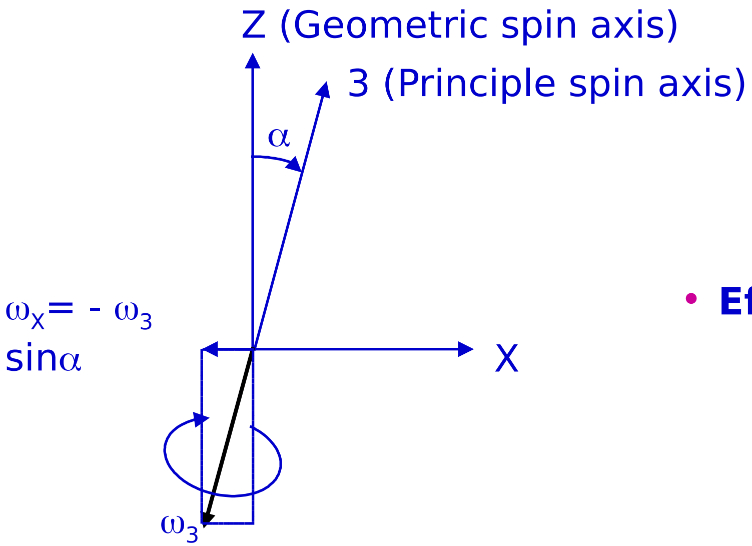
Estimated Body Rates Under Various Operational Conditions

- Ideal model with gravity gradient torque, 45 deg sun angle
  - Izz=800 (kg-m²), Ixx=Iyy=720, Ixy=0
  - No optical property variations
  - No geometry / deployment errors
- 30 to 3000 as spin axis misalignment
- 1 to 100 mm radial CM offset
- 0.4 to 40 min spin period

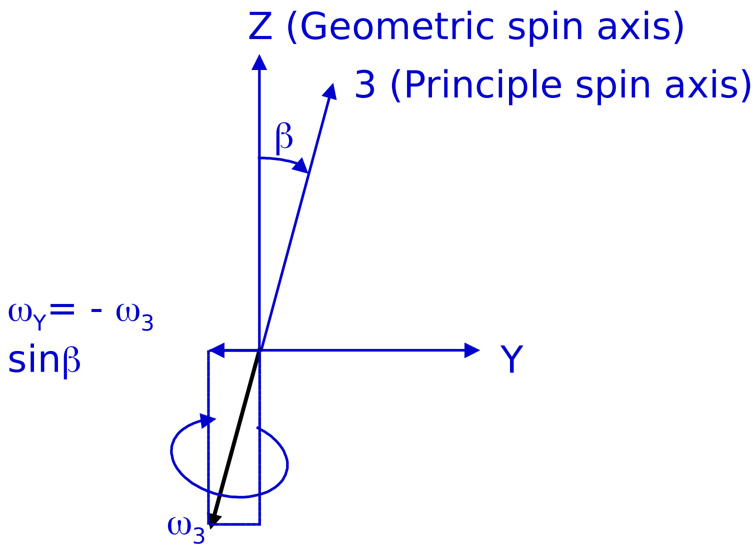


Influence of Spin Axis Misalignment on Body Rates

- **Effect of Ixz: misalignment in X-Z plane**

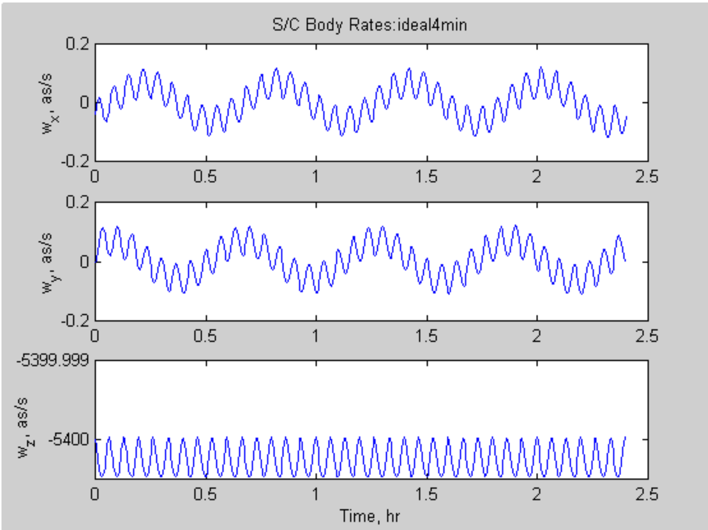


- **Effect of Iyz: misalignment in Y-Z plane**

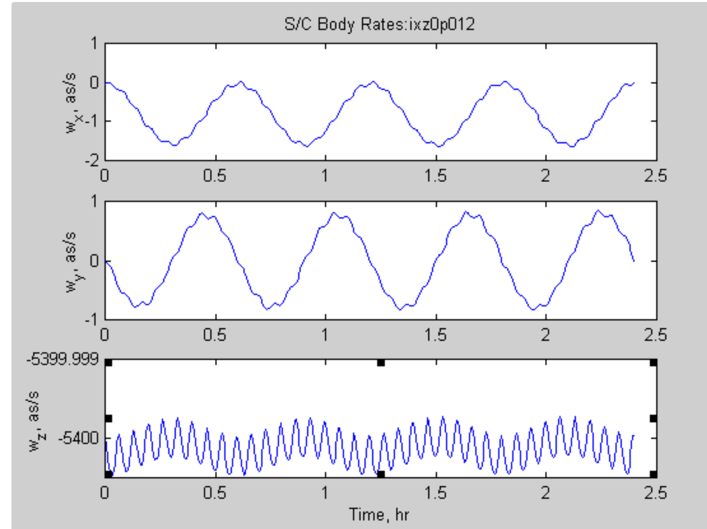


Influence of Misalignment on Body Rates (4 Min. Spin Period Data)

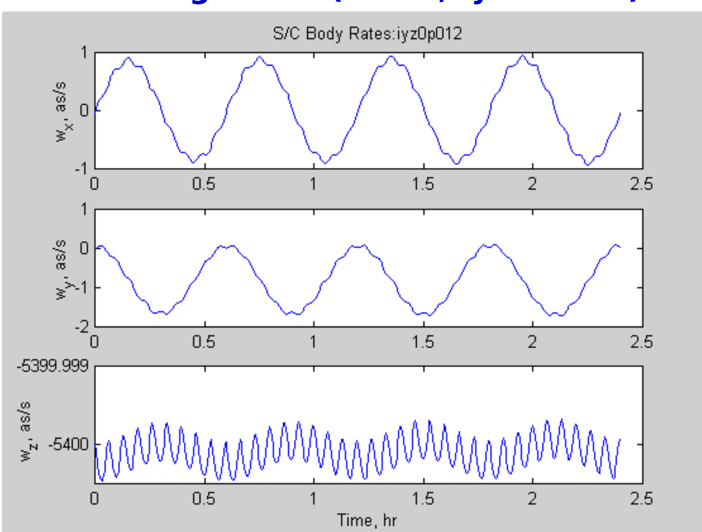
- **Zero misalignment (Ixz=Iyz=0)**



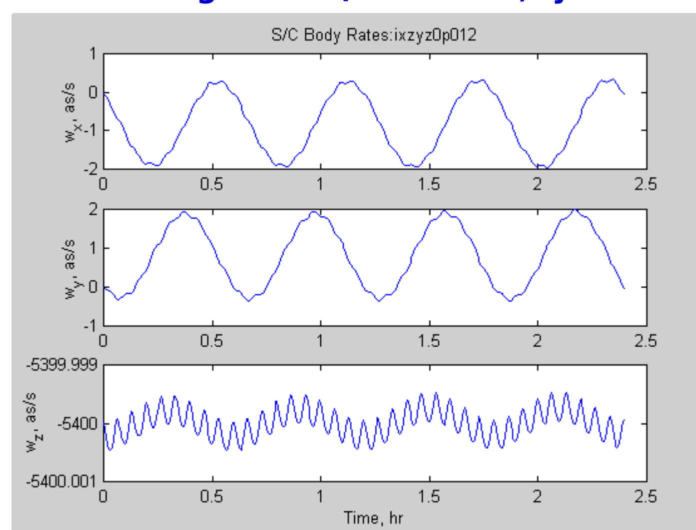
- **30 as misalignment (Ixz=0.012 kg-m2, Iyz=0)**



- **30 as misalignment (Ixz=0, Iyz=0.012)**

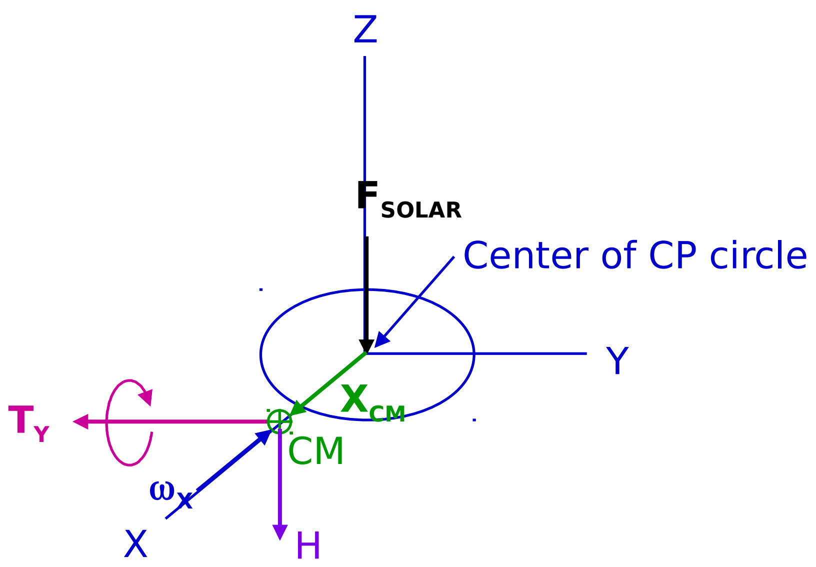


- **30 as misalignment (Ixz=0.012, Iyz=-0.012)**



Influence of Center of Mass Offset on Body Rates

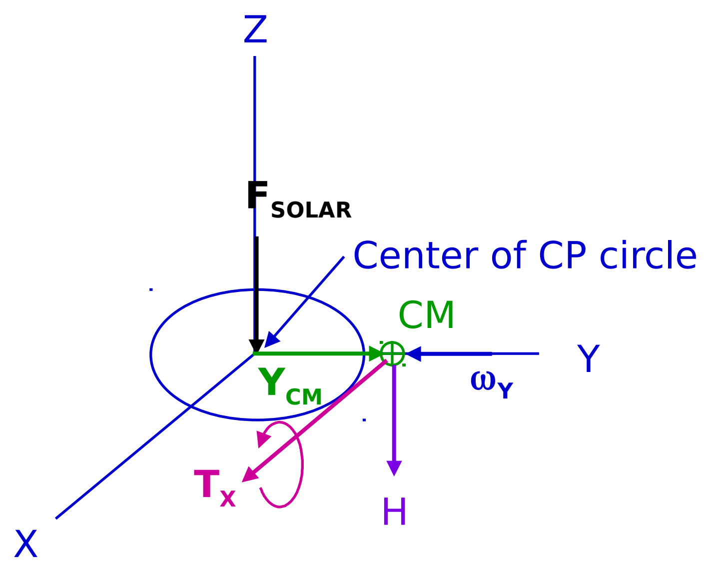
- **Effect of X_{CM} offset**



ω_X X H = T_Y

- Produces bias body rate along X axis

- **Effect of Y_{CM} offset**

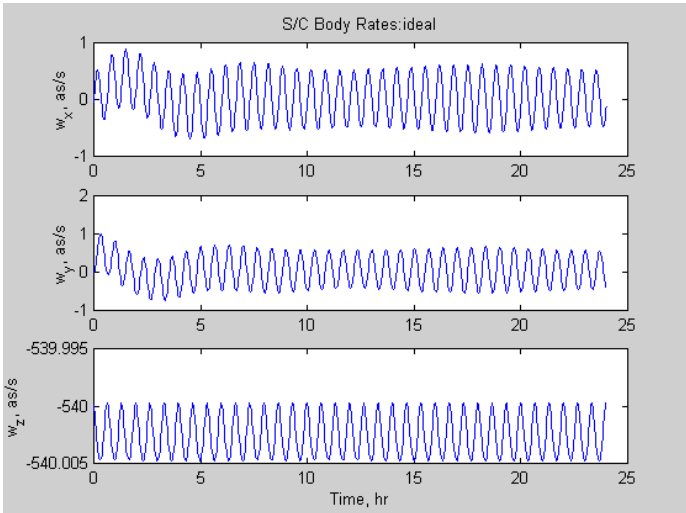


ω_Y X H = T_X

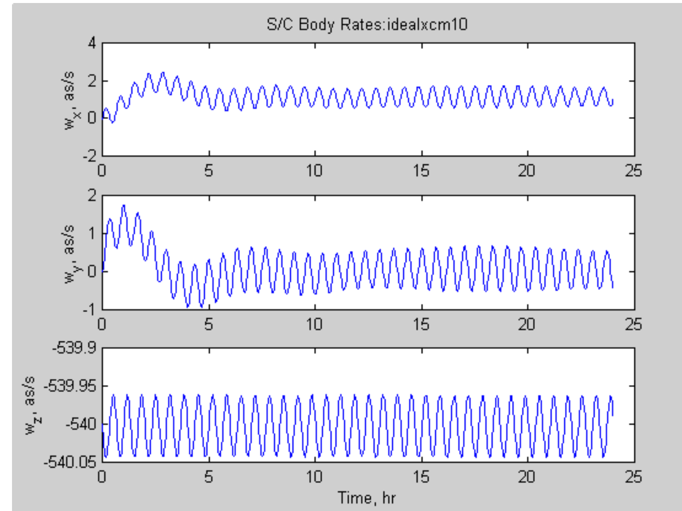
- Produces bias body rate along Y axis

Influence of CM Offset on Body Rates
(40 Min. Spin Period Data)

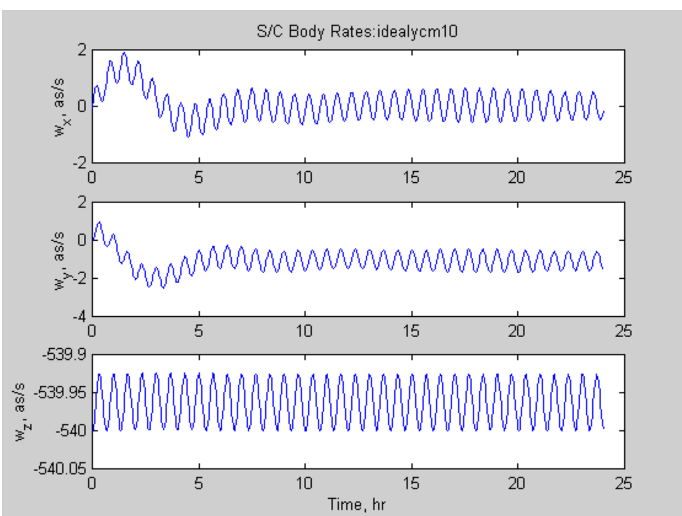
- **Zero CM offset ($X_{CM}=Y_{CM}=0$)**



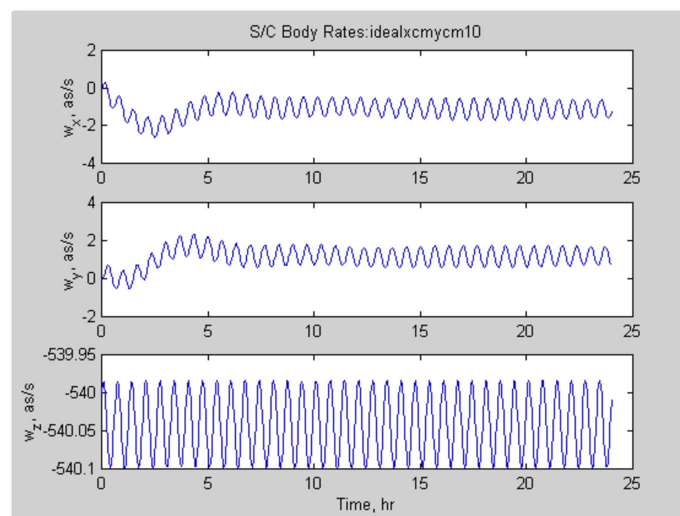
- **CM offset ($X_{CM}=-10mm$, $Y_{CM}=0$)**



- **CM offset ($X_{CM}=0$, $Y_{CM}=10mm$)**



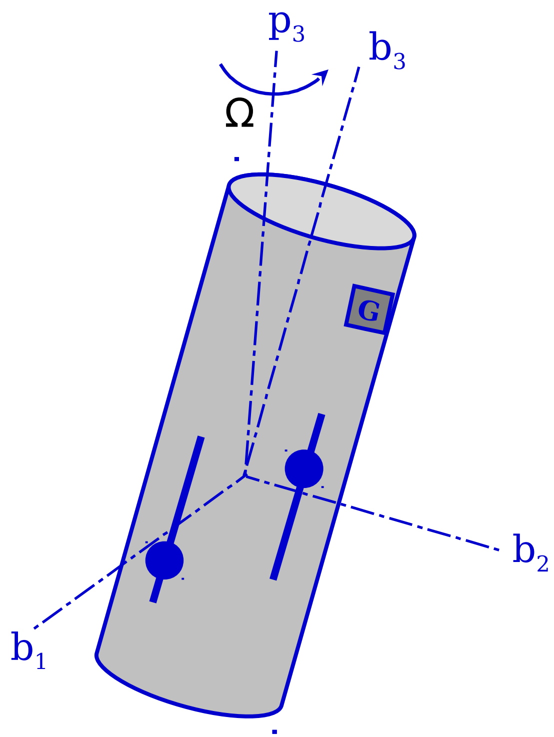
- **CM offset ($X_{CM}=10mm$, $Y_{CM}=-10mm$)**



On-Orbit Balancing and CM Estimation: Summary

- Assume IMU spin rate measurement bias of less than 1 as/s (1 deg/hr).
- On-Orbit Balancing (Misalignment Control) Scenario
  - Spin at 0.25 to 1 rpm with sun shield deployed
  - Measure transverse body rate biases using IMU
  - Adjust trim masses to reduce the biases and thus the misalignment below 30 as
- CM Estimation Scenario
  - Despin to 40 min period (0.025 rpm)
  - Measure transverse body rate bias changes using IMU
  - Estimate CM offset magnitude and direction for CP control
- Repeat the on-orbit balancing process as needed

FAME Spin Axis Balancing Using Gyros
Geometry and Strategy



G = three-axis gyro aligned with body fra

Ω = spin rate about principal spin axis

p_3 = principal spin axis

= I_{xz} and I_{yz} trim mass devices

The balancing goal is to adjust the trim masses to null the biases in the g
therefore removing the products of inertia (I_{xz} , I_{yz}) and aligning p_3 with b

FAME Spin Axis Balancing Using Gyros
Equations of Motion

Approximate Rotational Equations For Small Products of Inertia And Transverse Rates

$$\dot{\omega}_x + \bar{\Omega}^2 \omega_x = \frac{(I_{zz} - I_{yy})}{I_{xx} I_{yy}} I_{xz} \Omega^3$$

$$\dot{\omega}_y + \bar{\Omega}^2 \omega_y = \frac{(I_{zz} - I_{xx})}{I_{xx} I_{yy}} I_{yz} \Omega^3$$

$$\bar{\Omega}^2 = \frac{(I_{zz} - I_{xx})(I_{zz} - I_{yy})}{I_{xx} I_{yy}} \Omega^2$$

Time-Averaged Rates

$$\bar{\omega}_x \approx \frac{I_{xz}\Omega}{(I_{zz} - I_{xx})}$$

$$\bar{\omega}_y \approx \frac{I_{yz}\Omega}{(I_{zz} - I_{yy})}$$

Balancing Scheme

$$\bar{\omega}_x \Rightarrow 0$$

$$\bar{\omega}_y \Rightarrow 0$$

FAME Spin Axis Balancing Using Gyros
Systematic Gyro Errors

Gyro Output Model

$$\omega_{Gx} = \omega_x(1+\mu_x) + b_x + \beta_x\Omega + \text{noise}$$

$$\omega_{Gy} = \omega_y(1+\mu_y) + b_y + \beta_y\Omega + \text{noise}$$

μ_x, μ_y **= gyro scale factor errors**

b_x, b_y **= gyro bias errors**

β_x, β_y **= gyro misalignment errors**

Quantitative sensitivity of the spin axis balancing methodology to thes errors needs to be assessed to define requirements on gyro specificati spin rate, and ground processing filters.

FAME Spin Axis Balancing Using Gyros
Gyro Scale Factor Error Sensitivity

Time-Averaged Gyro Outputs

$$\overline{\omega}_{Gx} = \overline{\omega}_x (1 + \mu_x)$$

$$\overline{\omega}_{Gy} = \overline{\omega}_y (1 + \mu_y)$$

Resulting Spin Axis Balance Errors

$$I_{xz} \Rightarrow 0$$

$$I_{yz} \Rightarrow 0$$

Since nulling the gyro-measured averaged transverse rates nulls the true rates, spin axis balance errors are insensitive to gyro scale facto

FAME Spin Axis Balancing Using Gyros
Gyro Bias Error Sensitivity

Time-Averaged Gyro Outputs

$$\overline{\omega}_{Gx} = \overline{\omega}_x + b_x$$

$$\overline{\omega}_{Gy} = \overline{\omega}_y + b_y$$

Resulting Spin Axis Balance Errors

$$I_{xz} \Rightarrow -\frac{(I_{zz} - I_{xx})}{\Omega} b_x$$

$$I_{yz} \Rightarrow -\frac{(I_{zz} - I_{yy})}{\Omega} b_y$$

Spin axis balance errors due to gyro biases are proportional to the ratio o and the spin rate. The faster the spin rate, the smaller the resulting bala

Additionally, nulling the difference signal between averaged outputs at tw rates eliminates the sensitivity to gyro bias entirely.

FAME Spin Axis Balancing Using Gyros
Gyro Misalignment Error Sensitivity

Time-Averaged Gyro Outputs

$$\bar{\omega}_{Gx} = \bar{\omega}_x + \beta_x \Omega$$
$$\bar{\omega}_{Gy} = \bar{\omega}_y + \beta_y \Omega$$

Resulting Spin Axis Balance Errors

$$I_{xz} \Rightarrow -(I_{zz} - I_{xx})\beta_x$$
$$I_{yz} \Rightarrow -(I_{zz} - I_{yy})\beta_y$$

Spin axis balance errors due to gyro misalignments are proportional to the
The gyro misalignment errors represent the largest error sources during sp

FAME Spin Axis Balancing Using Gyros
Numerical Example Using An LN-200S Gyro

Spin Axis Alignment Requirement: I_{xz}, I_{yz} < $9.5\text{x}10^{-6}\, I_{zz}$

Spacecraft Inertias: $I_{xx} = I_{yy} = 720$ kg-m^2
$I_{zz} = 800$ kg-m^2

Gyro Parameters (3σ):
- **Scale Factor = 300 ppm**
- **Bias = 0.3 deg/hr (after on-board estimation)**
- **Internal Misalignment = 0.017 deg = 61 arcsec**
- **External Misalignment = 0.05 deg = 180 arcsec**

Spin Axis Balancing Errors:
- **Scale Factor Error, --> I_{xz}, I_{yz} = 0**
- **Bias Error (1 rpm) --> I_{xz}, I_{yz} = $1.5\text{x}10^{-6}\, I_{zz}$**
- **Internal Misalignment Error --> I_{xz}, I_{yz} = 30x10-**
- **External Misalignment Error --> I_{xz}, I_{yz} = 87x10-**
- **RSS --> I_{xz}, I_{yz} = $92\text{x}10^{-6}\, I_{zz}$**

Gyro Alignment Requirement (Internal + External): 19 arcsec (3σ)

FAME Spin Axis Balancing Using Gyros

Example of Rate Time-Averaging Using An LN-200S Gyro

Spacecraft Inertias: $I_{xx} = I_{yy} = 720$ kg-m²

$I_{zz} = 800$ kg-m²

$I_{xy} = 2$ kg-m²

$I_{xz} = 4\times10^{-5}\, I_{zz}$ $I_{yz} = -4\times10^{-5}\, I_{zz}$

Gyro Angle Random Walk = 0.1 deg/rt-hr

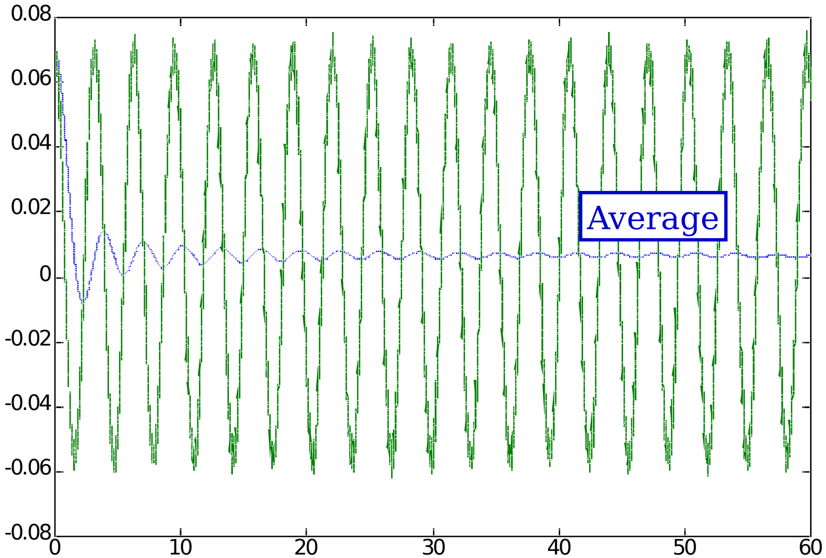
Sample Rate = 2 Hz

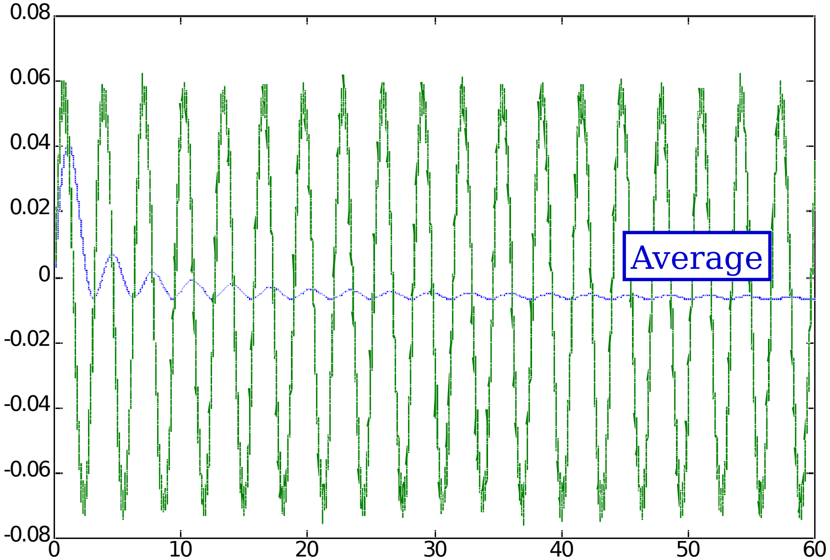
Spin Rate = 3 rpm

Nutational Angle = 0.2 deg

Estimated Averages: $w_{xave} = +0.007$ deg/sec $w_{yave} = -0.007$ deg/sec

Computer Simulation





Optical Property Verification Testing Plan

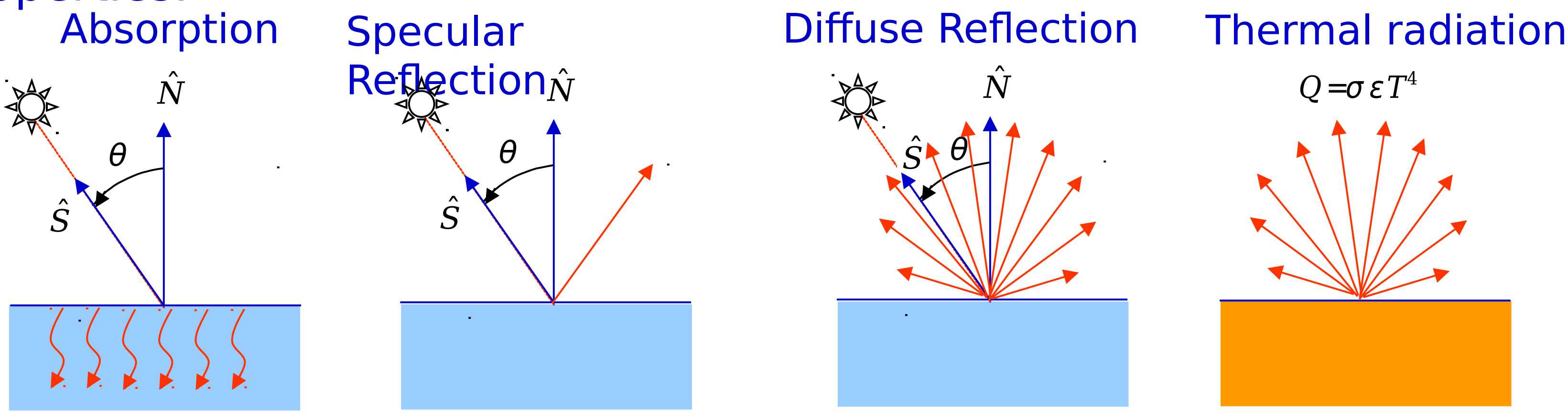
Technical Interchange Meeting
March 20-21, 2001
Naval Research Laboratory

Optical Property Measurement Requirements

- Absorption, reflection and emission coefficients
  - Measurement accuracy of +/- 0.025 (TBR)
  - Identify specular and diffuse fraction of reflection: measurement accuracy of +/- 0.05 (TBR)
  - Wave length range of full spectrum of solar radiation
- Optical property variations at 30 to 60 deg (45 deg nominal) sun (incident) angle and at 0 degree
- Point-to-point optical property variation of solar panels, webs, trim tabs, electronics decks, and AKM hole
  - Identification of center of pressure and its variation as a function of sun angle and orientation of surface
- Materials to test
  - Silver Teflon (for solar panel, web, electronics deck, and AKM hole)
  - Solar cells (for solar panel)
  - MLI (for electronics decks and shear panels)
- Beginning-of-life (BOL) and end-of-life (EOL) optical properties
  - EOL of either 2.5 or 5 years
  - Identification of optical property degradation rate change

Optical Property Definition and Corresponding Solar Radiation Force/Torque

- Solar radiation pressure force due to optical properties:



$$df_a = -PC_a \cos\theta \hat{S} dA \quad df_s = -2PC_s \cos^2\theta \hat{N} dA \quad df_d = -PC_d \left(\frac{2}{3} \cos\theta \hat{N} + \cos\theta \hat{S} \right) dA$$

$$C_a + C_s + C_d = 1$$

- Total reaction force on a flat surface of area A:

$$\underline{F} = -PA(\hat{S} \cdot \hat{N})[(1 - C_s)\hat{S} + 2(C_s(\hat{S} \cdot \hat{N}) + C_d / 3)\hat{N}] + Thermal$$

- Solar radiation torque:

$$\underline{T} = \underline{R}_{cp} \times \underline{F}$$

Small Test Specimen

- Reflectometer and BRDF (Bidirectional Reflectance Distribution Function) tests
- Size:
  - 1 inch by 1 inch (function of test equipment)
- Construction
  - Substrate: aluminum honeycomb with composite face sheets (thickness same as solar panels, webs, and electronics decks)
  - Test materials are attached to the substrate consistent with actual bonding process
- Number
  - TBD specimens for each material

Large Test Specimen

- For optical property variation measurements of large surface area and CP estimation
- Flight quality hardware of solar panels, webs, electronics decks, and trim tabs
- Size of test grids: TBD

ADCS Action Item Summary

Technical Interchange Meeting
March 20-21, 2001
Naval Research Laboratory

ADCS Action Items - Overview (1 Of 3)

- Action: R-23. Sun shield flatness and thermal requirements/costs. Can flatness and thermal errors be adjusted? Can a better second axis trim tab be used?
  - Due 19 March 2001
  - Assigned By Mark Johnson
- Action: R-40. Control rotation rate smoothly without thrusters.
  - Due 15 March 2001
  - Assigned By Ken Seidelmann
- Action: R-51. Resolve number of pixels in cross scan that are needed for precession and other effects.
  - Due: 5 February 2001
  - Assigned By Ken Johnston
- Action: R-53. If different amounts of power are drawn from the individual solar cells, will this result in a thermal torque? What is its effect on the FAME observatories rotation?
  - Due: 18 September 2001
  - Assigned By Ken Johnston
- Action: R-71, Can torque rods be used for active ACS control? (What percentage of time can they be used, can we still meet mission accuracy requirements?)
  - Due: 15 April 2001
  - Assigned By Ken Seidelmann

ADCS Action Items - Overview (2 Of 3)

- **Action: AI-61. Collect surface optical properties of solar array sun shield. Schedule testing if necessary.**
  - **Due: 5 September 2000**
  - **Assigned By Mark Johnson**
- **Action: AI-62. Decide whether AKM hole needs to be covered for solar precession.**
  - **Due 5 September 2000**
  - **Assigned By Mark Johnson**
- **Action: AI-65. Determine whether heaters should be pursued in place of trim tabs.**
  - **Due 5 September 2000**
  - **Assigned By Mark Johnson**

ADCS Action Items - Overview (3 Of 3)

- **Action: R-76. Determine the accuracy of the spacecraft attitude supplied to the instrument by the spacecraft bus ADCS.**
  - **Due: 20 March 2001**
  - **Assigned By Scott Horner**
- **Action: R-77. Determine the accuracy of the spacecraft rotation rate supplied to the instrument by the spacecraft bus ADCS.**
  - **Due: 20 March 2001**
  - **Assigned By Scott Horner**
- **Action: R-78. Determine the accuracy to which the Observatory mass properties will be adjusted so the Observatory rotation axis matches the geometric axis using only the spacecraft bus ADCS.**
  - **Due: 20 March 2001**
  - **Assigned By Scott Horner**

Sun Shield Flatness and Thermal Torque

Action R-23

- Sun shield flatness and thermal requirement/costs.
  - SRR flatness requirement of 2 mm over 5 m for solar panels seems achievable. It includes manufacturing error and thermal deformation (potato chipping). Further study is needed for potato chipping effects.
  - Thermal radiation requirements including blanketing the back side of the array are no longer critical as they are accommodated by oversized trim tabs (See Revised Baseline Solar Precession Control).
- Can flatness and thermal errors be adjusted?
  - Center of Pressure (CP) bias due to flatness and thermal errors is corrected by trim areas (See Revised Baseline Solar Precession Control). Cyclic torque will be left uncontrolled since it requires trim tab/area control at the spin rate.
- Can a better second axis trim tab be used?
  - Adding a roll DOF to a trim tab for spin rate control complicates mechanism design.
  - Thermal heater can provide the needed function (See Thermal Thruster Trade Study).

Control Rotation Rate Smoothly Without Thrusters

Action R-40

- Rotation rate capability
  - Thrusters to acquire initial conditions for instrument operation
  - Thermal patches for fine control of bias spin torque
  - EMTs for augmentation of:
    - Thermal patches for large bias spin torque
    - Thrusters for acquisition of instrument operation initial conditions
    - Coarse spin rate changes with 40 rpm +/- 4 rpm instrument operation

Resolve Cross Scan Pixels Needed

Action R-51

- **Action: Resolve number of pixels in cross scan that are needed for precession and other effects.**
- **Response: Provided time history simulation results with cross scan pixel histograms to USNO showing performance using SRR baseline (4 pixels precession & 5 pixels other effects) and received confirmation from Ken Johnston that this could be tolerated.**

Solar Cell Power and Thermal Torque

Action R-53

- **If different amounts of power are drawn from the individual solar cells, will this results in a thermal torque?**
  - **Different amounts of power mean different optical properties and temperature for solar cells. To prevent cyclic disturbance torque generation, solar cell strands are arranged and operated symmetrically about the spin axis. Any bias torque can be adjusted by CP and trim tab control.**

Torque Rods for ACS Control

Action R-71

- Can torque rod be used for active ACS control?
  - Torque rods will not replace the solar radiation precession control. It will rather be used to augment the solar precession control in case optical property variations are larger than the trim tabs/areas are designed for.
- What percentage of time can they be used?
  - Availability of torque rods for precession and spin control is an important factor determining their size. The required capability of a torque rod is directly proportional to the availability. (See magnetic control studies).
- Can we still meet mission accuracy requirements?
  - The mission accuracy requirements will be met while the torque rods are capable of producing the torque needed to augment the solar radiation precession.

Accuracy Of S/C Attitude Estimate

Action R-76

- Accuracy Of The Attitude Provided To The Observatory @ 1 Hz Rate From The S/C Bus ADCS System Is Better Than +/-265 μrad (3σ).
- Assumptions:
  - Capability based on post-SRR revision of attitude knowledge requirement for instrument attitude acquisition.
  - Low vehicle rotation rate will not degrade star tracker operation.
  - Instrument acquisition will not be done when earth passes through the star tracker's bright object exclusion zone unless both star trackers operating.
    - Star trackers will experience up to a 10 min outage period as the earth passes through the star tracker's bright object exclusion zone.
    - Star trackers will not have any sun obscuration or s/c structure obscuration
  - Inertial measurement unit available for attitude determination all the time with 100 Hz output rate.
  - Attitude estimates meets requirement of 18 arcsec (1σ) per axis when star tracker updates available.
  - 1 Hz output available to instrument based on Kalman filter processing of the star tracker and inertial measurement unit data.

Accuracy Of S/C Rotation Rate Estimate

Action R-77

- **Accuracy Of The Rotation Rate Provided To The Observatory @ 1 Hz Rate From The S/C Bus ADCS System Is Better Than 5 μrad/sec.**
- **Background**
  - **Nominal Instrument Spin Rate Is 2.62 mrad/sec = 2620 μrad/sec**
    - **2.62 mrad/sec will result in a delta theta of 26.2 μrad in 0.01 sec (100 Hz). The LSB for the LN-200 is 1.9 μrad. A delta theta of 26.2 μrad would show up as 13 to 14 counts.**
  - **Earth Rate For Ground Testing Is 15 deg/hr = 15 arcsec/sec = 0.072 mrad/sec**
    - **0.072 mrad/sec will result in a delta theta of 0.72 μrad in 0.01 sec (100 Hz). A delta theta of 0.72 μrad would only be 0.4 counts which would not show up until sufficient delta theta is accumulated.**
    - **At 100 Hz the noise floor for a single sample is around 1 count.**
    - **Earth rate is below noise level of a single 100 Hz sample from LN-200 however by collecting as little as 10 seconds of data and processing it is clearly visible (0.72 μrad x 10 sec = 7.2 μrad = 3.8 counts).**
    - **Clementine KF could estimate the bias down to better than 1 deg/hr = 1 arcsec/sec = 4.8 μrad/sec**
    - **FAME baseline uses a better star tracker and the same gyros, so performance should be at least as good.**

Accuracy Of Observatory Mass Properties

Action R-78

- The Geometric Axis To Rotation Axis Misalignment Using S/C Sensors Will Be To TBR μrad.
- Background
  - Original Request: Determine the accuracy to which the Observatory mass properties will be adjusted so the Observatory rotation axis matches the geometric axis using only the spacecraft bus ADCS.
  - SRR requirement from S/C BUS TOP RQMTS section, page 5:
    - Alignment Of CCD To Spin Axis (2 μrad in 1.56 sec)
      - CCD to FPA: TBD
      - FPA to Spin Axis: 150 μrad (= 30 arcsec)
  - SRR requirement from S/C BUS - ADCS section, page 3:
    - Alignment of FPA to Principal Spin Axis: 150 μrad (= 30 arcsec)
  - Current effort focused on the following:
    - Misalignment of the geometric axis to the vehicle rotation axis < 150 μrad for payload operation (note: this does not include misalignment of the CCDs to the geometric axis)
  - Balance mass system sized to correct a 0.5 degree misalignment to 150 μrad however the measurement of this misalignment is still being investigated.

Surface Optical Property Data

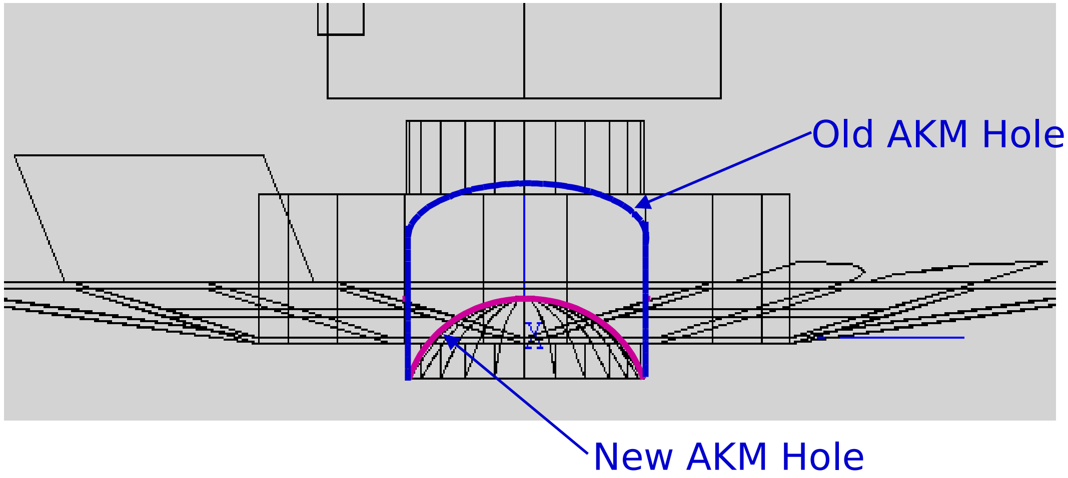
Action AI-61

- **Collect surface optical properties of solar array sun shield. Schedule testing if necessary.**
  - **See Optical Property Verification Testing Plan for details.**

AKM Hole Cover

Action AI-62

- **Decide whether AKM hole needs to be covered for solar precession.**
  - **There has been a significant change in the AKM hole geometry. It is no longer needed to cover the hole.**



Heaters for Precession Control

Action AI-65

- **Determine whether heaters should be pursued in place of trim tabs.**
  - **Precession control heaters are dropped due to excessive power requirements and operating concerns.**
  - **Spin control heaters are adapted for refined control in place for trim tabs with roll DOF.**
  - **See Thermal Thruster Trade Study for details.**